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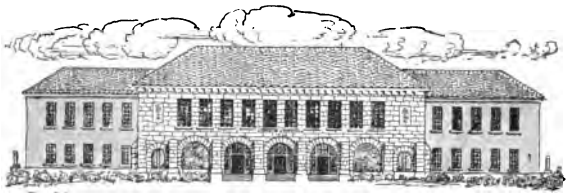

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OF

NATURAL PHILOSOPHY.

A TEXT-BOOK

FOR HIGH SCHOOLS AND ACADEMIES.

BY

ELROY M. AVERY, PH.M.,

PRINCIPAL OF THE EAST HIGH SCHOOL, CLEVELAND, OHIO.

ILLUSTRATED BY NEARLY 400 WOOD ENGRAVINGS.

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TO THE TEACHER.

IN this book will be found an unusual number of problems. It is not intended that each member of each class shall work all of the problems. It is hoped that they are sufficiently numerous and varied to enable you to select what you need for your particular class. No author can make a comfortable Procrustean bedstead.

You would do well to secure, in the fall of the year, a supply of the pith of elder or sunflower stalk, and several full-blown thistle-heads, that they may be well dried and ready for experiments in electricity during the dry, cold weather of winter.

The author would be glad to receive any suggestions from any of his fellow-teachers who may use this book, or to answer any inquiries concerning the study or apparatus.

Most of the apparatus mentioned in this book may be obtained from E. S. RITCHIE & SONS, Boston, or of N. H. EDGERTON, Philadelphia.

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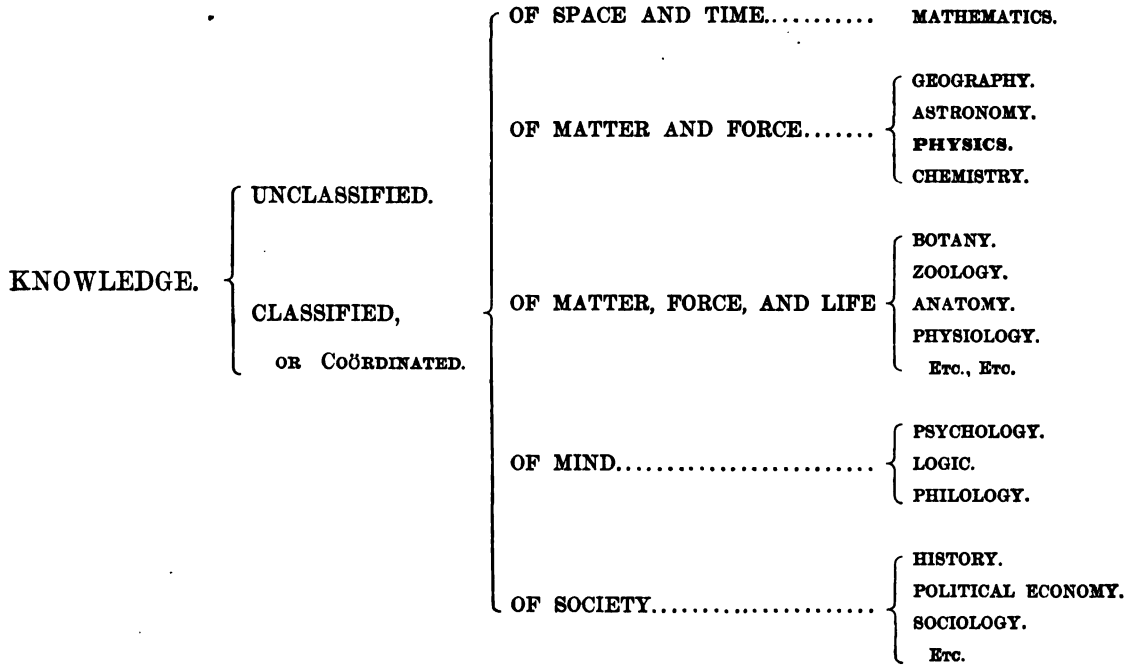
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SOCIOLOGY.
ETC.

CHAPTER I.

THE DOMAIN OF PHYSICS.—THE PROPERTIES OF MATTER.—THE THREE CONDITIONS OF MATTER.

SECTION I.

THE DOMAIN OF PHYSICS, OR NATURAL PHILOSOPHY.

Introductory.—On the page opposite, you have an outline map of the wide realm of human knowledge. As from a mountain top, you look upon the plain below, and clearly see the position of each province, and its relation to its neighbors. Through some of these provinces you may have passed, and with them have become more or less familiar. From the whole number we now select one that promises enough of interest and profit to justify the time and effort of careful study. Not satisfied with the cursory glance, we seek more definite information. For this, we must leave the peak and enter the plain; for though distance may lend an enchantment, it also begets a dimness fatal to our purpose.

1. What is Science?—*Science is classified knowledge.*

A person may have lived for years among plants, have acquired a vast store of information concerning them,

know that this one grows only in wet ground, that another is valuable for such and such an end, and that a third has certain form, size, and color. This general information may be valuable, but it is only when the facts are classified, and the plants grouped into their respective orders, genera and species, that the knowledge becomes entitled to the name of botany, *a science.*

2. What is Matter?—*Matter is anything that occupies space or "takes up room."*

There are many realities that are not forms of matter. Mind, truth, and hope do not occupy space; the earth and the rain-drop do.

3. Divisions of Matter.—*Matter may be considered as existing in masses, molecules, and atoms.*

A clear apprehension of the meaning of these terms is essential to a full understanding of the definition of Physics as well as of much else that follows.

4. What is a Mass?—*A mass is any quantity of matter that is composed of molecules.*

The word molar is used to describe such a collection of molecules.

(*a.*) The term mass also has reference to real quantity as distinguished from apparent quantity or size. A sponge may be compressed so as to seem much smaller than at first, but all of the sponge is still there. Its density is changed; its quantity or *mass* remains the same. This double use of the word is unfortunate, but the meaning in any given case may be easily inferred from the connection.

(*b.*) The quantity of matter constituting a mass is not necessarily great. A drop of water may contain a million animalcules; each animalcule is a mass as truly as the greatest monster of the land or sea. The dewdrop and the ocean, clusters of grapes and clusters of stars, are equally masses of matter.

5. What is a Molecule?—*A molecule is the smallest quantity of matter that can exist by itself.*

Molecules are exceedingly small, far beyond the reach of vision even when aided by a powerful microscope.

(*a.*) We know that a drop of water may be divided into several parts, and each of these into several others, each part still being water. The subdivision may be carried on until we reach a limit fixed by the grossness of our instruments and vision; each particle still is water. Even now, imagination may carry forward the work of subdivision until at last we reach a limit beyond which we cannot go without destroying the identity of the substance. In other words, we have a quantity of water so small that if we divide it again it will cease to be water; it will be something else. This smallest quantity of matter that can exist by itself and retain its identity is called a molecule. The word *molecule* means *a little mass.*

(*b.*) The smallest interval that can be distinctly seen with the microscope is about $\frac{1}{50000}$ inch. It has been calculated that about 2000 liquid water molecules might be placed in a row within such an interval. In other words, an aggregation of 8,000,000,000 water molecules is barely visible to the best modern microscopes.

6. What is an Atom?—*An atom is the smallest quantity of matter that can enter into combination.*

In nearly every case an atom is a part of a molecule.

(*a.*) If a molecule of water be divided, it will cease to be water at all, but will yield two atoms of hydrogen and one of oxygen. The molecule of common salt consists of one atom of sodium and one of chlorine. Some molecules are very complex. The common sugar molecule contains forty-five atoms.

(*b.*) Atoms make molecules; molecules make masses. Of the *absolute* size and weight of atoms and molecules little is known; of their *relative* size and weight much is known, and forms an important part of the science of chemistry.

7. Forms of Attraction.—Each of these three divisions of matter has its own form of attraction:

Molar attraction is called gravitation.

Molecular attraction is called cohesion or adhesion.

Atomic attraction is called chemical affinity (chemism).

8. Forms of Motion.—Each of these three divisions of matter has its own form of motion:

Molar motion, or visible mechanical motion, is called by different names according to the nature of the substance in motion; *e. g.*, the flow of a river or the vibrations of a pendulum.

Molecular motion, called heat, light, electricity, or magnetism.

Atomic motion. (Purely theoretical as far as known.)

9. Physical Science.—*Physical science comprises Physics and Chemistry.*

The first of these deals with masses and molecules; the second with atoms and combinations of atoms.

10. What is a Physical Change?—*A physical change is one that does not change the identity of the molecule.*

(*a.*) Inasmuch as the nature of a substance depends upon the nature of its molecules, it follows that a physical change is one that does not affect the identity of a substance. A piece of marble may be ground to powder, but each grain is marble still. Ice may change to water and water to steam, yet the identity of the substance is unchanged. A piece of glass may be electrified and a piece of iron magnetized, but they still remain glass and iron. These changes all leave the composition and nature of the molecule unchanged; they are physical changes.

11. What is a Chemical Change?—*A chemi-*

cal change is one that does change the identity of the molecule.

(*a.*) If the piece of marble be acted upon by sulphuric acid, a brisk effervescence takes place caused by the escape of carbonic acid gas which was a constituent of the marble; calcium sulphate (gypsum), not marble, will remain. The water may, by the action of electricity, be decomposed into two parts of hydrogen and one of oxygen. The nature of the glass and iron may easily be changed. These change the nature of the molecule; they are chemical changes.

12. Definition. — *Physics, or Natural Philosophy, is the branch of science that treats of the laws and physical properties of matter, and of those phenomena that depend upon physical changes.*

Recapitulation.—To be reproduced and amplified by the pupil for review.

Matter.		Divisions.	Attractions.	Motions.
PHYSICAL SCIENCE.	PHYSICS.....	MASSES.	GRAVITATION.	*Mechanical Power.*
		MOLECULES.	COHESION. ADHESION.	*Heat. Light. Electricity. Magnetism.*
	CHEMISTRY.	ATOMS.....	CHEMISM OR AFFINITY.	?

CHANGES. { PHYSICAL. CHEMICAL.

SECTION II.

THE PROPERTIES OF MATTER.

13. Properties of Matter.—*Any quality that belongs to matter or is characteristic of it is called a property of matter.*

Properties of matter are of two classes, physical and chemical.

14. What are Physical Properties?—*Physical properties are such as may be manifested without changing the identity of the molecule* (§ 10).

(*a.*) A piece of coal takes up room, it is hard and heavy, it cannot move itself. These several qualities or properties the coal may exhibit and still remain coal, or still retain its identity. They are, therefore, physical properties of coal.

15. What are Chemical Properties?—*Chemical Properties are such as cannot be manifested without changing the identity of the molecule* (§ 11).

(*a.*) A piece of coal may be burned; therefore combustibility is a property of the coal. This property has been held by the coal for countless ages, but it never has been shown. Further, this piece of coal never can show this property of combustibility without ceasing to exist as coal, without losing its identity. When the coal is burned, the molecules are changed from coal or carbon to carbonic acid gas (CO_2).

16. Experiment.—Take a piece of ordinary sulphur (brimstone) and attempt to pull it in pieces; the degree of its resistance to this effort, or its *tenacity*, measures the attraction of the molecules for each other. Strike it with a hammer, and it breaks into many pieces, thus manifesting its *brittleness;* but each piece is ordinary

sulphur. Heat it in a spoon, and it assumes the liquid form, but it is sulphur yet. In none of these changes has the nature of the molecule, or the identity of the substance, undergone any change. On the other hand, if the sulphur be heated sufficiently it will take fire and burn, producing the irritating, suffocating gas familiar to all through the use of common matches. We thus see that the sulphur is combustible. This combustibility is a chemical property, in the *manifestation* of which the identity of the substance is destroyed. Before the manifestation we had sulphur; after it we have sulphurous anhydride (SO_2). The original molecules were elementary, composed of like atoms; the resultant molecules are compound, composed of unlike atoms, sulphur and oxygen.

17. Division of Physical Properties.—Physical properties of matter are, in turn, divided into two classes, *universal* and *characteristic.*

18. What are Universal Properties?—*Universal properties of matter are such as belong to all matter.*

All substances possess them in common; no body can exist without them. We cannot even imagine a body that does not require space for its existence. This quality of matter, which will soon be named, is, therefore, universal.

19. What are Characteristic Properties?—*Characteristic properties of matter are such as belong to matter of certain kinds only.*

They enable us to distinguish one substance from an-

other. Glass is brittle, and by this single property may be distinguished from india-rubber.

20. List of Universal Properties.—The principal universal properties of matter are *extension, impenetrability, weight, indestructibility, inertia, mobility, divisibility, porosity, compressibility, expansibility, and elasticity.*

21. List of Characteristic Properties.—The characteristic properties of matter (often called *specific* or *accessory properties*) are numerous. They depend, for the most part, upon cohesion and adhesion. The most important characteristic properties are *hardness, tenacity, brittleness, malleability, ductility.*

22. What is Extension?—*Extension is that property of matter by virtue of which it occupies space.*

It has reference to the qualities of length, breadth, and thickness. It is an essential property of matter, involved in the very definition of matter.

(*a.*) All matter must have these three dimensions. We say that a line has length, a surface has length and breadth; but lines and surfaces are mere conceptions of the mind, and can have no material existence. The third dimension, which affords the idea of solidity or volume, is necessary to every form of every kind of matter. No one can imagine a body that has not these three dimensions, that does not occupy space, or "take up room." Figure or shape necessarily follows from extension.

23. English Measures.—For the purpose of comparing volumes, as well as surfaces and lengths, measures are necessary. In the United States and England the *yard* has been adopted as the unit, and its divisions, as

feet and inches, together with its multiples, as rods and miles, are in familiar use. This unit is determined by certain bars, carefully preserved by the governments of these two nations.

24. Metric Measures.—The international system has the merits of a less arbitrary foundation and of far greater convenience. From its unit it is known as the metric system. This system is in familiar use in most of the countries of continental Europe and by scientific writers of all nations, and bids fair to come into general use in this country. For these reasons, as well as for its greater convenience, an acquaintance with this system is now desirable, and will soon be necessary. It has been already legalized by act of Congress.

25. Definition of Meter.—The meter is defined as the *forty-millionth of the earth's meridian* which passes through Paris, or as the ten-millionth of a quadrant of such a meridian. It is *equal to 39.37 inches.* Like the Arabic system of notation and the table of U. S. Money, its divisions and multiples vary in a tenfold ratio.

26. Metric Measures of Length.—Ratio = 10.

Divisions.	*Millimeter*	(*mm.*) =	.001	*m.* =	0.03937 inches.
	Centimeter	(*cm.*) =	.01	*m.* =	0.3937 "
	Decimeter	(*dm.*) =	.1	*m.* =	3.937 "
Unit.	*Meter*	(*m.*) =	1.	*m.* =	39.37 "
Multiples.	Dekameter	(*Dm.*) =	10.	*m.* =	393.7 "
	Hektometer	(*Hm.*) =	100.	*m.* =	328 ft. 1 inch.
	Kilometer	(*Km.*) =	1000.	*m.* =	0.62137 miles.
	Myriameter	(*Mm.*) =	10000.	*m.* =	6.2137 "

FIG. 1.

Note.—The table may be read: 10 millimeters make 1 centimeter; 10 centimeters make 1 decimeter, etc. The denominations most used in practice are printed in italics. The system of nomenclature is very simple. The Latin prefixes, *milli-*, *centi-*, and *deci-*, signifying respectively 1000, 100, and 10, and already familiar in the mill, cent, and dime of U. S. Money, are used for the divisions, while the Greek prefixes *deka-*, *hekto-*, *kilo-*, and *myria-*, signifying respectively 10, 100, 1000, and 10000, are used for the multiples of the unit. Each name is accented on the first syllable.

27. Metric Measures of Surface.—Ratio = 10^2 = 100.

DIVISIONS.	Square millimeter	(*sq. mm.*)	= 0.000001 sq. m.
	Square centimeter	(*sq. cm.*)	= 0.0001 "
	Square decimeter	(*sq. dm.*)	= 0.01 "
UNIT.	Square meter	(*sq. m.*)	= 1. "
	etc., etc.		

Note.—The table may be read: 100 sq. mm. = 1 sq. cm.; 100 sq. cm. = 1 sq. dm., etc. The reason for the change of ratio from 10 to 100 may be clearly shown by representing 1 *sq. dm.*, and dividing it into *sq. cm.* by lines, which shall divide each side of the sq. dm. into 10 equal parts or centimeters.

28. Metric Measures of Volume.—Ratio = 10^3 = 1000.

DIVISIONS.	Cubic millimeter	(*cu. mm.*)	= 0.000000001 cu. m.
	Cubic centimeter	(*cu. cm.*)	= 0.000001 "
	Cubic decimeter	(*cu. dm.*)	= 0.001 "
UNIT.	*Cubic meter*	(*cu. m.*)	= 1.308 cu. yds.
	etc., etc.		

29. Metric Measures of Capacity.—Ratio = 10.—For many purposes, such as the measurement of articles usually sold by dry and liquid measures, a smaller unit than the cubic meter is desirable. For such purposes

the *cubic decimeter* has been selected as the standard, and when thus used *is called a liter* (pronounced *leeter*).

DIVISIONS.	Milliliter	(*ml.*) =	1 cu. cm.	= 0.061022 cu. in.
	Centiliter	(*cl.*) =	10 "	= 0.338 fld. oz.
	Deciliter	(*dl.*) =	100 "	= 0.845 gill.
UNIT.	*Liter*	(*l.*) =	1000 "	= 1.0567 liquid qts.
MULTIPLES.	Dekaliter	(*Dl.*) =	10 cu. dm.	= 9.08 dry qts.
	Hektoliter	(*Hl.*) =	100 cu. dm.	= 2 bu. 3.35 pks.
	Kiloliter	(*Kl.*) =	1 cu. m.	= 264.17 gals.

30. Comparative Helps.—It may be noticed that the *m.* corresponds somewhat closely to the yard, which it will replace. Kilometers will be used instead of miles. The *cu. cm.* may be represented by the ordinary die used in playing backgammon. The *l.* does not differ very much from the quart, or the *Dl.* from the peck, which they will respectively replace. In fact, the *l.* is, in capacity, intermediate between the dry and liquid quarts.

31. What is Impenetrability?—*Impenetrability is that property of matter by virtue of which two bodies cannot occupy the same space at the same time.*

(*a.*) Illustrations of this property are very simple and abundant. Thrust a finger into a tumbler of water; it is evident that the water and the finger are not in the same place at the same time. Drive a nail into a piece of wood; the particles of wood are either crowded more closely together to give room for the nail, or some of them are driven out before it. Clearly, the iron and the wood are not in the same place at the same time.

32. Experiment.—Through one cork of a two-necked bottle pass a small funnel or "thistle-tube," and let it extend nearly to the bottom of the bottle. Through

the other cork lead a tube to the water-pan, and let it terminate beneath or within the neck of a clear glass bottle filled with water, and inverted in the water-pan. See that the corks are air-tight; if necessary, seal them with wax or plaster of Paris. If a two-necked bottle be not convenient, substitute therefor a wide-mouthed bottle having two holes through the cork. The delivery tube is best made of glass. It may be easily bent by first heating it red-hot in an alcohol or gas flame. Pour water steadily through the funnel; as it descends, air is forced out through the delivery tube, and may be seen bubbling through the water in the inverted bottle. At the end of the experiment, the volume of water in the two-necked bottle will be nearly equal to the volume of air in the inverted bottle. This clearly shows the impenetrability of air.

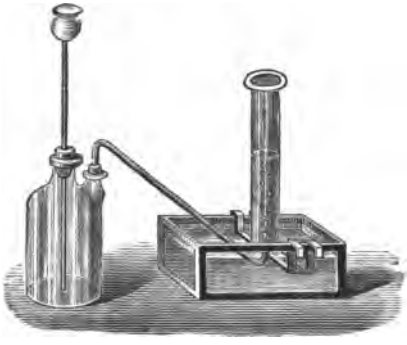


FIG. 2.

33. What is Weight?—*Weight is* (as the term is generally used) *the measure of gravity* or molar attraction (§ 7) of which it is a necessary consequence.

(*a.*) As all masses of matter exert this force, weight necessarily pertains to *all* matter; but, in general use, the term weight has reference to bodies upon the earth. If a body be placed near the earth's surface and left unsupported, the mass-attraction of the earth for each molecule in the body will draw the two together, and

the body is said to fall to the earth. But in this case we have no means of measuring the force that draws the two bodies together. If now the body be supported, the force acts as before and produces pressure upon the supporting substance. This pressure measures the attractive force acting between the earth and the body, and is called *weight*. If a second body like the first be placed beside it, the mass-attraction of the earth is exerted upon twice as many molecules, and, reciprocally, the attraction of twice as many molecules is exerted upon the earth; *i. e.*, the attraction has become twice as great, and the measure of that attraction, or the weight, has been doubled.

(*b.*) If the same body were upon the moon, its weight would be the measure of the attraction existing between the body and the moon. But as the mass of the moon is less than that of the earth, the attraction between the body and the moon would be less than that between that body and the earth, and the weight would be proportionally diminished.

34. English Measures of Weight.—For the comparison of weights, as well as of extension, standards are necessary. In England and the United States the pound is taken as the unit. Unfortunately, we have pounds Troy, Avoirdupois, and Apothecaries', the use varying with the nature of the transaction. As with the yard, these units are arbitrary, determined by certain carefully preserved standards.

35. Metric Measures of Weight.—Ratio = 10.

Divisions.	Milligram	(*mg.*)	= 0.0154	grains avoirdupois.
	Centigram	(*cg.*)	= 0.1543	" "
	Decigram	(*dg.*)	= 1.5432	" "
Units.	*Gram*	(*g.*)	= 15.432	" "
Multiples.	Dekagram	(*Dg.*)	= 0.3527	oz. "
	Hektogram	(*Hg.*)	= 3.5274	" "
	Kilogram	(*Kg.*)	= 2.2046	lbs. "
	Myriagram	(*Mg.*)	= 22.046	" "

t is a Gram?—*A gram is the weight . cm. of pure water,* at its temperature of ensity (4° C. or 39.2° F.). A 5-cent nickel coin g.

EXERCISES.

1. How much water, by weight, will a liter flask contain?
2. If sulphuric acid is 1.8 times as heavy as water, what weight of the acid will a liter flask contain?
3. If alcohol is 0.8 times as heavy as water, how much will 1250 *cu. cm.* of alcohol weigh?
4. What part of a liter of water is 250 *g.* of water?
5. What is the weight of a *cu. dm.* of water?
6. What is the weight of a *dl.* of water?

37. What is Indestructibility?—*Indestructibility is that property of matter by virtue of which it cannot be destroyed.*

(*a.*) Science teaches that the universe, when first hurled into space from the hand of the Creator, contained the same amount of matter, and even the same quantity of each element, that it contains to-day. This matter has doubtless existed in different forms, but during all the ages since, not one atom has been gained or lost. Take carbon for instance. From geology we learn that in the carboniferous age, long before the advent of man upon the earth, the atmosphere was highly charged with carbonic acid gas, which, being absorbed by plants, produced a vegetation rank and luxuriant beyond comparison with any now known. The carbon thus changed from the gaseous to the solid form was, in time, buried deep in the earth, where it has lain for untold centuries, not an atom lost. It is now mined as coal, burned as fuel, and thus transformed again to its original gaseous form. No human being can create or destroy a single atom of carbon or of any other element. Matter is indestructible. Water evaporates and disappears only to be gathered in clouds and condense and fall as rain. Wood burns, but the ashes and smoke contain the identical atoms of which the wood was composed. In a different form, the matter still exists and weighs as much as before the combustion.

38. What is Inertia?—*Inertia is that property of matter by virtue of which it is incapable*

of changing its condition of rest or motion, or the property by virtue of which it has a tendency when at rest to remain at rest, or when in motion to continue in motion.

(*a.*) If a ball be thrown, it requires external force to put it in motion; the ball cannot put itself in motion. When the ball is passing through the air it has no power to stop, and it will not stop until some external force compels it to do so. This external force may be the bat, the catcher, the resistance of the air, or the force of gravity. It must be something *outside the ball* or the ball will move on forever. Illustrations of the inertia of matter are so numerous that there should be no difficulty in getting a clear idea of this property. The "running jump" and "dodging" of the play-ground, the frequent falls which result from jumping from cars in motion, the backward motion of the passengers when a car is suddenly started and their forward motion when the car is suddenly stopped, the difficulty in starting a wagon and the comparative ease of keeping it in motion, the "balloon" and "banner" feats of the circus-rider, etc., etc., may be used to illustrate this property of matter.

39. Experiment.—Upon the tip of the fore-finger of the left hand, place a common calling-card. Upon this card, and directly over the finger, place a cent. With the nail of the middle finger of the right hand let a sudden blow or "snap" be given to the card. A few trials will enable you to perform the experiment so as to drive the card away, and leave the coin resting upon the finger. Repeat the experiment with the variation of a bullet for the cent, and the open top of a bottle for the finger-tip.

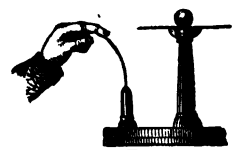


FIG. 3.

40. What is Mobility?—*Mobility is that property of matter by virtue of which the position of bodies may be changed.*

(*a.*) A body is any separate portion of matter, be it large or small, as a book, a table, or a star. The term is nearly synonymous with mass, but has not so distinct a reference to the absolute quantity of matter. Bodies or masses are composed of molecules; molecules are composed of atoms.

(*b.*) On account of inertia, the body cannot change its own position; on account of mobility any mass of matter may be moved if sufficient force be applied. This changing of position is called *motion;* motion presupposes force. (See § 64.)

41. What is Divisibility?—*Divisibility is that property of matter by virtue of which a body may be separated into parts.*

(*a.*) Theoretically, the atom is the limit of divisibility of matter. Practically the divisibility of matter is limited before the molecule is reached; our best instruments are not sufficiently delicate, our best trained senses are not acute enough for the isolation or perception of a molecule. Nevertheless, this divisibility may be carried to such an extent, by natural, mechanical (physical) or chemical means, as to excite our wonder and test the powers of imagination itself. It is said that the spider's web is made of threads so fine that enough of this thread to go around the earth would weigh but half a pound, and that each thread is composed of six thousand filaments. A single inch of this thread with all its filaments may be cut into thousands of distinct pieces, and each piece of each filament be yet a mass of matter composed of molecules and atoms. The microscope reveals to us the existence of living creatures so small that it would require thousands of millions of them to aggregate the size of a hemp-seed. Yet each animalcule has organs of absorption, etc.; in some of these organs fluids circulate or exist. How small must be the molecules of which these fluid *masses* are composed! What about the size of the atoms which constitute the molecules? A coin in current use loses, in the course of a score of years, a perceptible quantity of metal by abrasion. What finite mind can form a clear idea of the amount of metal rubbed off at each transfer?

42. What is Porosity?—*Porosity is that property of matter by virtue of which spaces exist between the molecules.*

(*a.*) When iron is heated, the molecules are pushed further apart, the pores are enlarged, and we say that the iron has expanded. If a piece of iron or lead be hammered, it will be made smaller, because the molecules are forced nearer together, thus reducing the size of the pores. Cavities or cells, like those of bread or sponge, are sometimes spoken of as "sensible pores," but these are not properly included under this head.

43. What is Compressibility?—*Compressibility is that property of matter by virtue of which a body may be reduced in size.*

44. What is Expansibility?—*Expansibility is that property of matter by virtue of which a body may be increased in size.*

(*a.*) Compressibility and expansibility are the opposites of each other, resulting alike from porosity. Illustrations have been given under the head of porosity. Let each pupil prove by experiment that air is compressible and expansible.

45. What is Elasticity?—*Elasticity is that property of matter by virtue of which bodies resume their original form or size when that form or size has been changed by any external force.*

(*a.*) All bodies possess this property in some degree, because all bodies, solid, liquid or aeriform, when subjected to pressure (within limits varying with the substance), will resume their original size upon the removal of the pressure. The amount of compression matters not except in the case of solids. It was formerly thought that liquids were incompressible; hence aeriform bodies were called elastic fluids, while liquids were called non-elastic fluids. But the compressibility and perfect elasticity of liquids having been shown, the term "non-elastic fluid" involves a contradiction of terms and would better be dropped. Fluids have no elasticity of form; on the other hand, all fluids have perfect elasticity of size. What properties of matter are illustrated by the action of the common pop-gun?

46. What are Cohesion and Adhesion?—*Cohesion is the force that holds together like mole-*

cules; adhesion is the force that holds together unlike molecules.

FIG. 4.

(*a.*) Cohesion is the force that holds most substances together and gives them form. Were cohesion suddenly to cease, brick and stone and iron would crumble to finest powder, and all our homes and cities and selves fall to hopeless ruin. In aeriform bodies, cohesion is not apparent, being overcome by molecular repulsion (heat). In large masses of liquids the cohesive force is overcome by gravity, which tends to bring all the molecules as low as possible and thus renders their surfaces level. But in small masses of liquids, the cohesive force predominates and draws all the molecules as near each other as possible, and thus gives to each mass the spheroidal form, as in the case of the dew or rain-drop. Globules of mercury upon the hand or table, and drops of water upon a heated stove, are familiar illustrations of this effect of cohesion upon small liquid masses. But in the solid state of matter, cohesion shows most clearly. Cohesion acts only at insensible (molecular) distances. Let the parts of a body be separated by a sensible distance, and cohesion ceases to act; we say that the body is broken. If the molecules of the parts can again be brought within molecular distance of each other, cohesion will again act and hold them there. This may be done by simple pressure, as in the case of wax or freshly-cut lead; it may be done by welding or melting, as in the case of iron. Circular plates of glass or metal, about three inches in diameter, often have their faces so accurately fitted to each other that, when pressed together, a considerable force is needed to separate them. (See Fig. 4.)

(*b.*) Adhesion is the force that causes the pencil or crayon to leave traces upon the paper or blackboard, and gives efficacy to paste, glue, mortar and cements generally. In a brick wall, cohesion binds together the molecules of the mortar layer into a single, hardening mass, while on either hand adhesion reaches out and grasps the adjoining bricks and holds them fast—a solid wall. Like cohesion, it acts only through distances too small to be measured; unlike cohesion, it acts between unlike molecules.

47. What is Hardness?—*Hardness is that property of matter by virtue of which some bodies resist any attempt to force a passage between their particles.*

It is measured by the degree of difficulty with which it is scratched by another substance. Fluids are not said to have hardness.

(*a.*) Hardness does not imply density. The diamond is much harder than gold, but gold is four times as dense as diamond.

48. What is Tenacity?—*Tenacity is that property of matter by virtue of which some bodies resist a force tending to pull their particles asunder.*

(*a.*) Like hardness and the other characteristic properties of matter, it is a variety of cohesion which is the general term for the force which holds the molecules together and prevents disintegration. The tenacity of a substance is generally ascertained by shaping it in the form of a rod or wire, the area of whose cross-section may be accurately measured. Held by one end in a vertical position, the greatest weight which the rod will support is the measure of its tenacity. For any given material, it has been found that *the tenacity is proportioned to the area of the cross-section; e. g.*, a rod with a sectional area of a square inch will carry twice as great a load as a rod of the same material with a sectional area of a half square inch; a rod one decimeter in diameter will carry four times as great a load as a similar rod five centimeters in diameter. The explanation of this is simple; *imagine* these rods to be cut across, and it will be evident that, on each side of the cut, the first rod will expose the surfaces of twice as many molecules as will the second, and that the third will expose four times as many molecular surfaces as the fourth. But for the same material, each molecule has the same attractive force. Doubling the number of these attractive molecules, which is done by doubling the sectional area, doubles the total attractive or cohesive force, which, in this case, is called tenacity; quadrupling the sectional area quadruples the tenacity. Hence the law: Tenacity is proportioned to the sectional area.

49. What is Brittleness?—*Brittleness is that property of matter by virtue of which some bodies may be easily broken, as by a blow.*

(*a.*) Glass furnishes a familiar example of this property. The idea that brittleness is the opposite of hardness, elasticity or tenacity, should be guarded against. Glass is harder than wood, but

very brittle; it is very elastic, but very brittle also. Steel is far more tenacious than lead, and far more brittle.

50. What is Malleability?—*Malleability is that property of matter by virtue of which some bodies may be rolled or hammered into sheets.*

(*a.*) Steel has been rolled into sheets thinner than the paper upon which these words are printed. Gold is the most malleable metal, and, in the form of gold leaf, has been beaten so thin that 282,000 sheets, placed one upon the other, would measure but a single inch in height.

51. What is Ductility?—*Ductility is that property of matter by virtue of which some bodies may be drawn into wire.*

(*a.*) Platinum wire has been made $\frac{1}{10000}$ of an inch in diameter. Glass, when heated to redness, is very ductile.

52. Experiment.—Heat the middle of a piece of glass tubing, about six inches long, in an alcohol flame, until red-hot. Roll the ends of the glass slowly between the fingers, and when the heated part is soft, quickly draw the ends asunder. That the fine glass wire thus produced is still a tube, may be shown by blowing through it into a glass of water, and noticing the bubbles that will rise to the surface.

Recapitulation.—To be reproduced and amplified by the pupil from memory.

- PROPERTIES OF MATTER.
  - CHEMICAL.
  - PHYSICAL.
    - GENERAL.....: *Extension, Impenetrability, Weight, Indestructibility, Inertia, Mobility, Divisibility, Porosity, Compressibility, Expansibility, Elasticity.*
    - CHARACTERISTIC.
      - ADHESION.
      - COHESION.

      Hardness. Tenacity. Brittleness. Malleability. Ductility.

SECTION III.

THE THREE CONDITIONS OF MATTER.

53. Conditions of Matter.—*Matter exists in three conditions or forms—the solid, the liquid, and the aeriform.*

54. What is a Solid?—*A solid is a body whose molecules change their relative positions with difficulty.*

Such bodies have a strong tendency to retain any form that may be given to them. A movement of one part of such a body produces motion in all of its parts.

55. What is a Liquid?—*A liquid is a body whose molecules easily change their relative positions, yet tend to cling together.*

Such bodies adapt themselves to the form of the vessel containing them, but do not retain that form when the restraining force is removed. They always so adapt themselves as to have their free surfaces horizontal. Water is the best type of liquids.

56. Experiment.—Suspend a glass or metal plate, of about four inches area, from one end of a scale-beam, and accurately balance the same with weights in the opposite scale-pan. The supporting cords may be fastened to the plate with wax. Beneath

FIG. 5.

the plate place a saucer so that when the saucer is filled with water the plate may rest upon the liquid surface, the scale-beam remaining horizontal. Carefully add small weights to those in the scale-pan. Notice that the water *beneath the plate* is raised above its level. Add more weights until the plate is lifted from the water. Notice that the under surface of the plate is wet. These molecules on the plate have been torn from their companions in the saucer. The weights added to the original counterpoise were needed to overcome the tendency of the water molecules to cling together.

Note to the Pupil.—After seeing a physical experiment, always ask yourself, "What was the object of that experiment? What does it teach?" Never allow yourself to look upon an experiment as being simply entertaining; thus reducing the experimenter, *so far as you are concerned*, to the level of a showman.

57. What is an Aeriform Body?—*An aeriform body is one whose molecules easily change their relative positions, and tend to separate from each other almost indefinitely.*

Atmospheric air is the best type of aëriform bodies.

58. Gases and Vapors.—Aëriform (having the form of air) bodies are of two kinds, *gases* and *vapors*. Gases remain aëriform under ordinary conditions, although some, if not all, may be liquefied by intense cold and pressure. *Vapors* are aëriform bodies produced by heat from substances that are generally solid or liquid, as iodine or water. They resume the solid or liquid form at the ordinary temperature.

59. Changes of Condition.—The same substance may exist in two or even three of these forms. Most

solids, as lead and iron, may be changed by heat to liquids; others, as iodine, may be apparently changed directly to vapors; still others, as ice, may be easily changed first to the liquid, and then to the vapor form. It is probable that any solid might be liquefied and vaporized by the application of heat, and that the practical infusibility of certain substances is due to our limited abilities in the production of heat.

(*a.*) Many vapors and gases, as steam and sulphurous anhydride (SO_2, the irrespirable gas formed by burning sulphur), may be liquefied by cold, the withdrawal of heat. The process is one of subtraction. A still further diminution of the heat force would, in many cases, lead to a solidifying of the liquid. It is probable that all gases might be liquefied and all liquids solidified, if we had the power of unlimited withdrawal of heat. In fact, it is claimed that the last of the "permanent gases" has been liquefied already.

60. What is a Fluid?—*A fluid is a body whose molecules easily change their relative positions.*

The term comprehends liquids, gases, and vapors.

61. Optional Definitions.—(1.) A body possessing any degree of elasticity of form (§ 45) is a solid; a body that possesses no elasticity of form is a fluid.

(2.) A body that can exist in equilibrium under the action of a pressure that is not uniform in all directions is a solid; a body that cannot exist in equilibrium under such conditions is a fluid.

(3.) A fluid that can expand indefinitely so as to fill any vessel, however large, is an aëriform body; a fluid, a small portion of which, when placed in a large vessel, does not expand at once so as to fill the vessel, but remains collected at the bottom, is a liquid.

62. Test Questions.—What is the one characteristic difference between a solid and a liquid? Between a liquid and a gas? Between a gas and a vapor? Between a fluid and a solid? Into what two classes may these three physical conditions of matter be divided, reference being made only to ease or difficulty of a change of relative position of the molecules?

Recapitulation.—To be reproduced, upon paper or the blackboard, by each pupil.

- MATTER
  - **SOLIDS.** Molecules change their relative positions with difficulty.
  - **FLUIDS.** Molecules change their relative positions easily.
    - **LIQUIDS.** Molecules cling together feebly.
    - **AËRIFORM BODIES.** Molecules tend to separate.
      - GASES; *ordinarily aëriform.*
      - VAPORS; *ordinarily liquid or solid.*

CHAPTER II.

DYNAMICS.—FORCE AND MOTION.—GRAVITATION.—FALLING BODIES.—THE PENDULUM.—ENERGY.

SECTION I.

FORCE AND MOTION.

63. Dynamics.—*Dynamics is that branch of physics which treats of forces and their effects.*

These effects may be of two kinds.

(*a.*) The forces employed may be counterbalanced. If they thus act upon a body at rest, that body will remain at rest; if they act upon a body in motion, the motion will not be changed thereby. The branch of dynamics that treats of forces thus balanced is called *Statics.*

(*b.*) The forces employed may act against the inertia of matter (§ 38), and produce motion or change of motion. The branch of dynamics that treats of forces thus used is called *Kinetics.* If we have a problem relating to the forces that may produce equilibrium in a lever, as in the act of weighing goods, it is a static problem; if a problem refer to the velocity of a falling body, or the amount of work that may be done by the uncoiling of a watch-spring, it is a kinetic problem.

Note.—No attempt will be made to maintain the distinction between the static and kinetic effects of forces.

64. What is Force?—The word *force* is difficult of satisfactory definition. As generally used, *it signifies*

any cause that tends to produce, change, or destroy motion.

It follows from inertia that bodies are incapable of changing their condition of rest or motion. Any cause capable of producing a tendency to change either of these conditions, is called a force.

(*a.*) We say that the *tendency* of a force acting on a body at rest is to move it. Motion *will* be produced if the body is free to move. This motion may be prevented by the simultaneous action of another force or of other forces. Or the body may be fixed so that a given pull or pressure, *i. e.*, the application of force, will produce no motion. In this case, opposing forces are called into action as soon as the given force begins to act, and thus the new force is neutralized. For instance, a small boy may exert all of his muscular power upon a large stone and not lift it at all. The force employed produces no motion. The attraction between the earth and the stone (§ 33) is a force acting in a downward vertical direction. This force is exactly balanced by the upward pressure of the supporting earth or floor (§ 93). If the stone weighs two hundred pounds and the boy lifts fifty pounds, the supporting body exerts an upward pressure of only one hundred and fifty pounds. One quarter of the weight of the stone or a downward force of fifty pounds is thus liberated or called into play by the very act of lifting with a force of fifty pounds. Hence no motion is produced, because an opposing force is called into action as soon as the given force begins to act, and thus the new force is neutralized.

(*b.*) In this case, the greatest opposing force that can be set free or called into play is a force of two hundred pounds, the full weight of the stone. If, therefore, the stone be lifted with a force of more than two hundred pounds, the new force can not be wholly neutralized and motion will take place. If there be no opposing force to be thus called into action, or, in other words, if the body be free to move, the smallest conceivable force will overcome the inertia and produce motion.

65. Elements of a Force.—In treating of forces, we have to consider three things:

(1.) *The point of application,* or the point at which the force acts.

(2.) *The direction*, or the right line along which it tends to move the point of application.

(3.) *The magnitude* or value when compared with a given standard, or the relative rate at which it is able to produce motion in a body free to move.

66. Measurement of Forces.—It frequently is desirable to compare the magnitudes of two or more forces. That they may be compared, they must be measured; that they may be measured, a standard of measure or unit of force is necessary. When this unit has been determined upon, the value of any given force is designated by a numerical reference to the unit, just as we refer quantities of weight to the kilogram or pound, or quantities of distance to the meter or yard. The magnitude of any force may be measured by either of two units, which we shall now consider.

67. The Gravity Unit.—The given force may be measured by comparing it with the gravity of some known quantity or mass of matter. This is a very simple and convenient way, and often answers every purpose. *The gravity unit of force is the gravity of any unit of mass.* This unit of mass may be a gram, kilogram, pound, or ton, or any other unit that may be more convenient under the circumstances.

(*a.*) A force is said to be a force of 100 kilograms when it may be replaced by the action of a weight of 100 kilograms. The pressure of steam in a boiler is generally measured, at present, in pounds *per* square inch, that is, by determining the number of pounds with which it would be necessary to load down a movable horizontal square inch at the top of the boiler in order to keep it in place against the pressure of the steam. A cord or rope may be pulled with a certain force. This force is measured by finding out how

many pounds suspended by the cord or rope would give it an equal pull or tension.

(*b.*) As we shall see, the force of gravity exerted upon a given mass is variable. A given piece of iron would weigh more at the poles than at the equator. Other variations in the force of gravity are known. When, therefore, scientific accuracy is required, it will not suffice to speak of a force of ten pounds, but we may speak of a force of ten pounds at the sea-level at New York City. The necessary corrections may then be made. But for ordinary purposes, these details may be disregarded.

68. The Absolute Unit.—*The absolute or kinetic unit of force is the force that, acting for unit of time upon unit of mass, will produce unit of velocity.*

If we adopt the common units, the kinetic unit of force is the force that, applied to one pound of matter for one second, will produce a velocity of one foot per second.

(*a.*) In all kinetic questions the kinetic unit is far more convenient. Gravity units may easily be changed to kinetic units. At the latitude of New York, the force of gravity acting upon one pound of matter left free to fall will give it a velocity of 32.16 ft. per second for every second that it acts. Consequently, at such latitudes, the gravity unit is equal to 32.16 kinetic units.

69. The Dyne.—Instead of using a unit of force based upon the foot and pound, scientific men are coming to use a similar unit based upon the centimeter and gram. This unit has recently received a definite name. *The dyne is the force which, acting for one second upon a mass of one gram, produces a velocity of one centimeter per second.*

(*a.*) If a body weighing 25 grams acquires in one second a velocity of 30 cm. the moving force was 750 dynes. If it acquires the same velocity in 2 seconds, of course the force was only half as great, or 375 dynes.

(*b.*) The several units based upon the centimeter, gram and second,

constitute a class called (from the initial letters of these words) C. G. S. Units. Thus the dyne is the C. G. S. unit of force.

Note to the Pupil.—We have been speaking of unit of mass, and you have probably had no difficulty in understanding that, by this term, a certain definite quantity of matter is meant. This certain quantity may be *any* quantity that we agree upon as a unit of measure. In this country we have, as yet, no commonly accepted unit of mass. In countries where the metric system of weights and measures is used, the unit of mass is the quantity of matter contained in one *cu. cm.* of pure water at its temperature of greatest density. It will be seen that this definition is independent of gravity, and that it holds good for matter anywhere. The quantity of matter in the unit thus defined is invariable, while the gram, which is its weight (§ 36), is variable. But notwithstanding this, *at any given place*, weight is proportional to mass, and we, therefore, conveniently use weight as a means of estimating mass. We speak without any considerable ambiguity of a pound of matter, because we know that a mass that weighs two pounds at the same place has just twice as much matter as the first, which we may take as a convenient unit of mass.

70. Momentum.—*The momentum of a body is its quantity of motion.*

Its measure is the product of the numbers representing the mass and the velocity.

(*a.*) One tendency of force is to produce motion. Two units of force will produce twice as much motion as one unit. This doubled momentum or quantity of motion may exist in two units of mass having one unit of velocity, or in one unit of mass with two units of velocity. The momentum of a body having a mass of 20 pounds and a velocity of 15 feet, is twice as great as that of a body having a mass of 5 pounds and a velocity of 30 ft. The momentum of the former is 300; that of the latter, 150. Momentum has reference only to force and inertia. Therefore, when acting upon bodies free to move, equal forces will produce equal momenta whether the bodies acted upon be light or heavy. The unit of momentum has no definite name.

71. Experiment.—Figure 6 represents a piece of apparatus, devised by Ritchie of Boston. It consists of

two ball pendulums, one of which weighs twice as much as the other, suspended as represented. The heavier ball contains a spring-hammer, which is held back by a thread. The hammer being thus held back, and the smaller ball resting against its face, the thread is burned, a blow is struck, and an equal force is exerted upon each ball (§§ 72 [3] and 93). The smaller ball will move twice as fast and twice as far as the larger ball, equal forces producing equal momenta.

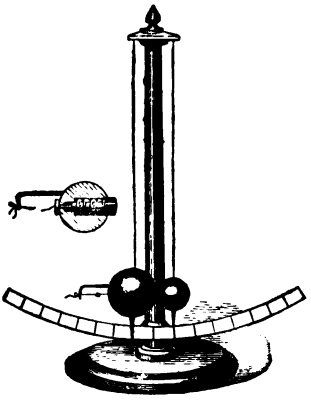


FIG. 6.

EXERCISES.

1. Find the momentum of a 500 lb. ball moving 500 feet a second.

2. By falling a certain time, a 200 lb. ball has acquired a velocity of 321.6 ft. What is its momentum?

3. A boat, that is moving at the rate of 5 miles an hour, weighs 4 tons; another, that is moving at the rate of 10 miles an hour, weighs 2 tons. How do their momenta compare?

4. What is meant by a force of 10 pounds? To how many kinetic units is it equal?

5. A stone weighing 12 oz. is thrown with a velocity of 1320 ft. per minute. An ounce ball is shot with a velocity of 15 miles per minute. Find the ratio between their momenta.

6. An iceberg of 50,000 tons moves with a velocity of 2 miles an hour; an avalanche of 10,000 tons of snow descends with a velocity of 10 miles an hour. Which has the greater momentum?

7. Two bodies weighing respectively 25 and 40 pounds have equal momenta. The first has a velocity of 60 ft. a second; what is the velocity of the other?

8. Two balls have equal momenta. The first weighs 100 kilo-

grams and moves with a velocity of 20 meters a second. The other moves with a velocity of 500 meters a second. What is its weight?

9. A force of 1000 dynes acts on a certain mass for one second and gives it a velocity of 20 cm. *per* second. What is the mass in grams? *Ans.* 50.

10. A constant force, acting on a mass of 12 g. for one second, gives it a velocity of 6 cm. *per* second. Find the force in dynes.

11. A force of 490 dynes acts on a mass of 70 g. for one second. What velocity will be produced? *Ans.* 7.

12. Two bodies start from a condition of rest and move towards each other under the influence of their mutual attraction (§§ 7 and 98). The first has a mass of 1 g.; the second, a mass of 100 g. The force of attraction is $\frac{1}{100}$ dyne. What will be the velocity acquired by each during one second?

72. Laws of Motion.—The following propositions, known as Newton's Laws of Motion, are so important and so famous in the history of physical science that they ought to be remembered by every student:

(1.) Every body continues in its state of rest or of uniform motion in a straight line unless compelled to change that state by an external force.

(2.) Every motion or change of motion is in the direction of the force impressed and is proportionate to it.

(3.) Action and reaction are equal and opposite in direction.

73. The First Law.—The first law of motion results directly from inertia (§ 38). It is impossible to furnish perfect examples of this law because all things within our reach or observation are acted upon by some external force. A base-ball when once set in motion has no power to stop itself (§ 38, *a*). If it moved in obe-

dience to the muscular impulse only, its motion would be in a straight line; but the force of gravity is ever active, and constantly turns it from that line, and forces it to move in a graceful curve instead.

74. Centrifugal Force.—Although it is obviously impossible to give any direct experimental proof of the first

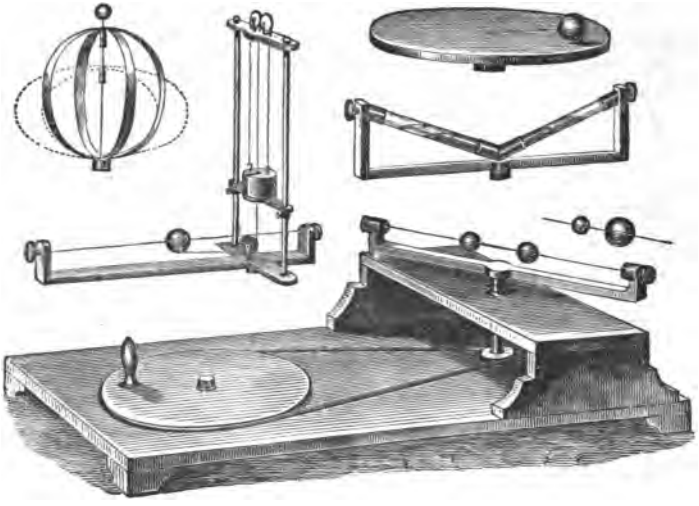


FIG. 7.

law of motion, we see many illustrations of the *tendency* of moving bodies to move in straight lines even when forced to move in curved lines. A curved line may be considered a series of infinitely small straight lines. A body moving in a curve has, by virtue of its inertia, a tendency to follow the prolongation of the small straight line in which it chances to be moving. Such a prolongation becomes a tangent to the curve, to move in which a body must fly further from the centre. *This tendency*

of matter to move in a straight line, and, consequently, further away from the centre around which it is revolving, is called Centrifugal Force, from the Latin words which mean to fly from the centre. The "laws" of this "centrifugal force" may be studied or illustrated by the *whirling-table* and accompanying apparatus, represented in Figure 7. (See § 77.)

75. Caution.—It is to be noticed that this so-called *"Centrifugal Force" is not a force at all.* It is simply inertia manifested under special conditions. It is one of the universal properties of matter by virtue of which the body shows a decided determination to obey the first law of motion. The facts of the case are the direct opposite of those implied by this ill-chosen name. Take a common sling, for instance. The *implication* is that the pebble in the revolving sling has a natural tendency to continue moving in a circle, and that some external force is necessary to overcome that tendency. The *truth* is that the natural tendency of the pebble is to move in a straight line, and the only reason that it does not thus move is that it is continually forced from its natural path by the pull of the string. As soon as this external force is removed, by intent or accident, away flies the stone in obedience to its own law-abiding tendencies.

76. Simply Suggestive.—Examples and effects of this so-called centrifugal force may be suggested as follows: Wagon turning a corner, railway curves, water flying from a revolving grindstone, broken fly-wheels, spheroidal form of the earth, erosion of river-beds, a pail of water whirled in a vertical circle, the inward leaning of the circus-horse and rider, the centrifugal drying apparatus of the laundry

or sugar refinery, difference between polar and equatorial weights of a given mass, etc.

77. *Note.*—Mathematical formulæ for measuring the force necessary to overcome this tendency of matter to move away from the centre around which it may be revolving, or, as it is generally expressed, for measuring the centrifugal force, may be found in the Appendix. It is sufficient here to mention that this force varies directly as the mass and as the square of the velocity, the radius remaining the same; doubling the mass doubles the force needed, but doubling the velocity quadruples the needed restraining force.

78. The Second Law.—The second law of motion is sometimes given as follows: *A given force will produce the same effect whether the body on which it acts is in motion or at rest; whether it is acted on by that force alone or by others at the same time.*

(*a.*) Many attempts have been made to show that there are only two ways of stating the same proposition; most of them are more perplexing than profitable. In the law as given by Newton (§ 72), the word *motion* is doubtless used in the sense of *momentum*. If the substitution of "momentum" for "motion" makes the reconciliation any easier, no objection can be made to the substitution.

79. Resultant Motion.—*Motion produced by the joint action of two or more forces is called resultant motion.*

The point of application, direction, and magnitude of each of the acting forces being given, the direction and magnitude of the resultant force are found by a method known as the *composition of forces.*

80. Composition of Forces.—Under composition of forces, three cases may arise:

(1.) *When the given forces act in the same direction.* The resultant is then the sum of the given forces. Example: Rowing a boat down stream.

(2.) *When the given forces act in opposite directions.* The resultant is then the difference between the given forces. Motion will be produced in the direction of the greater force. Example: Rowing a boat up stream.

(3.) *When the given forces act at an angle.* The resultant is then ascertained by the parallelogram of forces. Example: Rowing a boat across a stream.

81. Graphic Representation of Forces.— *Forces may be represented by lines,* the point of application determining one end of the line, the direction of the force determining the direction of the line, and the magnitude of the force determining the length of the line.

(*a.*) It will be noticed that these three elements of a force (§ 65) are the ones that precisely define a line. By drawing the line as above indicated, the units of force being numerically equal to the units of length, we have a complete graphic representation of the given force. The unit of length adopted in any such representation may be determined by convenience; but the scale once determined, it must be adhered to throughout the problem. Thus the diagram represents two forces applied to the point B. These forces act at right angles to each other. The arrowheads indicate that the forces represented act from B toward A and C respectively. The force that acts in the direction BA being 20 pounds and the force acting in the direction BC being 40 pounds, the line BA must be one-half as long as BC. The scale adopted being 1 *mm.* to the pound, the smaller force will be represented by a line 2 *cm.* long, and the greater force by a line 4 *cm.* long.

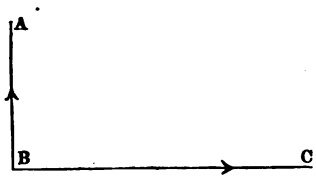


FIG. 8.

(*b.*) The graphic determination or representation of the resultant in the first two cases under the "Composition of Forces" is too simple to need any explanation.

82. Parallelogram of Forces.—In the diagram, let AB and AC represent two forces acting upon the point A. Draw the two dotted lines to complete the parallelogram. From A, the point of application, draw the diagonal AD. *This diagonal will be a complete graphic representation of the resultant.* In such cases the two given forces are called *components.* The resultant of any two components may always be determined in this way. If two forces, such as those represented in the diagram, act simultaneously upon a body at A, that body will move over the path represented by AD, and come to rest at D.

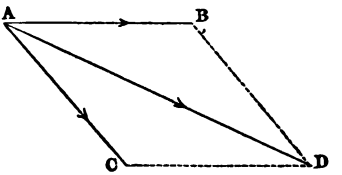


FIG. 9.

(*a.*) Suppose that instead of acting simultaneously, these forces act successively. If AC act first for a given time, it would move the body to C. If then the other force act for an equal time it would move it to the right a distance represented by AB or its equal CD, and the body be left at D as before. If the force represented by AB acted first and the force represented by AC then acted for an equal time, the body would evidently be left at D. Thus we see that these two forces produce the same effect whether they act simultaneously or successively.

83. Experimental Verification.—This principle of the parallelogram of forces may be verified by the apparatus represented in Fig. 10. ABCD is a very light wooden frame, jointed so as to allow motion at its four corners. The lengths of opposite sides are equal; the lengths of adjacent sides are in the ratio of two to three. From the corners B and C, light, flexible silk cords pass over the pulleys M and N, and carry weights, W and *w*, of 90 and 60 ounces respectively, the ratio between the

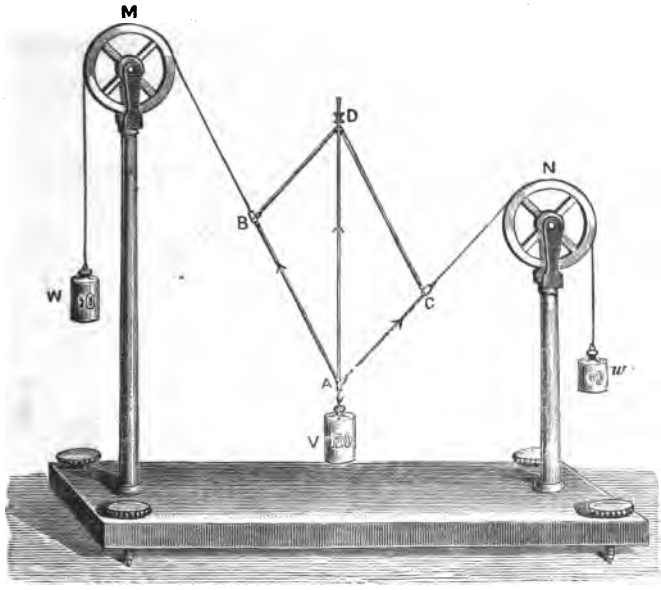


FIG. 10.

weights being the same as the ratio between the corresponding adjacent sides of the wooden parallelogram. A weight of 120 ounces is hung from the corner A. When the wooden frame comes to rest it will be found that the sides AB and AC lie in the direction of the cords which form their prolongations. These sides AB and AC are accurate graphic representations of the two forces acting upon the point A. It will be further found that the diagonal AD is vertical and twice as long as the side AC. Since the side AC represents a force of 60 ounces, AD will represent a force of twice 60 ounces or 120 ounces. We thus see that AD fairly represents the resultant of the two forces due to the gravity of W and *w*, for this result-

ant is equal, and opposite to the vertical force which is due to the gravity of V, and this balances the forces represented by AB and AC. Results equally satisfactory will be secured as long as AB : AC :: W : *w*.

84. A Substitute.—Very satisfactory results may be had by simpler apparatus. Let H and K represent two pulleys that work with very little friction. Fix them to a vertical board. The blackboard will answer well if the pulleys can be attached without injury. Three silk cords are knotted together at O; two of them pass over the pulleys; the three cords carry weights, P, Q, and R, as shown in the figure. R must be less than the sum of P and Q. When the apparatus has come to rest, take the points A and B so that AO : BO :: P : Q. Complete the parallelogram AOBD by drawing lines upon the vertical board. Draw the diagonal OD. It will be found by measurement that AO : OD :: P : R; or that BO : OD :: Q : R. Either equality of ratios affords the verification sought.

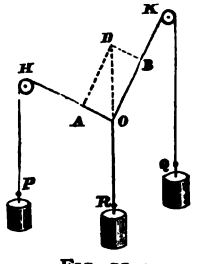


FIG. 11.

85. Determination of the Value of the Resultant.—With a carefully-constructed diagram (only half of the parallelogram need be actually drawn) the resultant may be directly measured and its value ascertained from the scale adopted. The value and direction of the resultant may be found trigonometrically, without actual construction of the diagram, when the angle between the directions of the components is known. In one or two cases, however, the mathematical solution is easy without

the aid of trigonometrical formulæ. When the components act at right angles to each other, the resultant is the hypothenuse of a right-angled triangle. (See *Olney's Geometry*, paragraph 346.) When the components are equal and include an angle of 120°, the resultant divides the parallelogram into two equilateral triangles. It is equal to either component, and makes with either an angle of 60°. (Let the pupil draw such a diagram.)

86. Equilibrant.—*A force whose effect is to balance the effects of the several components is called an equilibrant.* It is numerically equal to the resultant, and opposite in direction. Thus in Fig. 10, the gravity of the weight V is the equilibrant of W and w; it is equal and opposite to the resultant represented by AD.

87. Triangle of Forces.—By reference to Fig. 9, it will be seen that if AC represent the magnitude and direction of one component, and CD the magnitude and direction of the other component, the line AD, which completes the triangle, will represent the direction and intensity of the resultant. Where the point of application need not be represented, this method of finding the relative magnitudes and directions is more expeditious than the one previously given. If the line which completes the triangle be measured from D to A, that is to say, in the order in which the components were taken, it represents the equilibrant; the arrow-head upon AD should then be turned the other way. If this line be measured from A to D, that is, in the reverse order, it represents the resultant.

88. Composition of More than Two Forces.—If more than two forces act upon the point of application, the resultant of any two may be combined with a third, their resultant with a fourth, and so on. The last diagonal will represent the resultant of all the given forces. Suppose that four forces act upon the point A, as represented in the diagram. By compounding the two forces AB and AC, we get the partial resultant, Ar; by compounding this with AD, we get the second partial resultant, Ar'; by compounding this with AE, we get the resultant, AR.

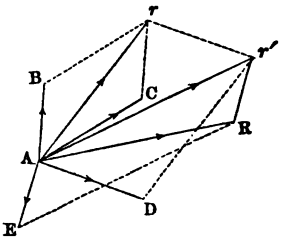


FIG. 12.

89. Polygon of Forces.—This resultant may be more easily obtained by the *polygon of forces*. If a number of forces be in equilibrium, they may be graphically represented by the sides of a closed polygon taken in order. If the forces are not in equilibrium, the lines representing them in magnitude and direction will form a figure which does not close. The line that completes the figure and closes the polygon will, when taken in the same order, indicated by the arrow-head at x, represent the equilibrant; when taken in the opposite order, indicated by the arrow-head at z, it will represent the resultant. This will be evident from a comparison of the diagram with the one preceding, the forces compounded being the same.

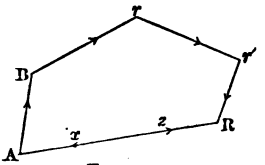


FIG. 13.

90. Parallelopiped of Forces.—The component forces may not all act in the same plane, but the method of composition is still the same. In the particular case of three such forces it will be readily seen that the resultant of the forces AB, AC, and AD is represented by AR, the diagonal of the parallelopiped constructed upon the lines representing these forces.

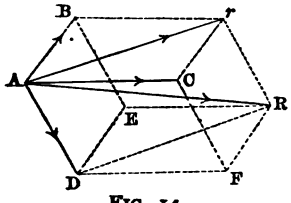


FIG. 14.

91. Resolution of Forces.—*The operation of finding the components to which a given force is equivalent is called the resolution of forces.*

It is the converse of the composition of forces. Represent the given force by a line. On this line as a diagonal construct a parallelogram. An infinite number of such parallelograms may be constructed with a given diagonal. When the problem is to resolve or decompose the given force into two or more components *having given directions*, it is definite—only one construction being possible. The sides that meet at the point of application will represent the component forces.

92. Example of Resolution of Forces.—As we proceed we shall find more than one example of the resolution of forces. A single one will answer in this place. It is a familiar fact that a sail-boat may move in a direction widely different from that of the propelling wind, and that, under such circumstances, the velocity of the boat is less than it would be if it were sailing in the direction of the wind. The force due to the pressure of the

wind is twice resolved, and only one of the components is of use in urging the boat forward. In Figure 15, let KL represent the keel of the boat; BC, the position of the sail; and AB, the direction and intensity of the wind. In the first place, when the wind strikes the sail thus placed, it is resolved into two components—BC parallel to the sail, and BD perpendicular to the sail. It is evident that the first of these is of no effect. But the boat does not move in the direction of BD, which is, in turn, resolved by the action of the keel and rudder into two forces, BL in the direction of the keel, and BE perpendicular to it. The first of these produces the forward movement of the boat; the second produces a lateral pressure or tendency to drift, which is more or less resisted by the build of the boat.

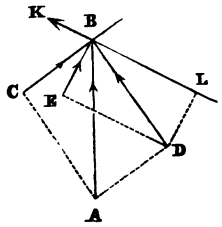


FIG. 15.

93. The Third Law.—Examples of the third law of motion are very common. When we strike an egg upon a table, the reaction of the table breaks the egg; the action of the egg may make a dent in the table. The reaction of the air, when struck by the wings of a bird, supports the bird if the action be greater than the weight. The oarsman urges the water backward with the same force that he urges his boat forward. In springing from a boat to the shore, the reaction of our muscular action tends to drive the boat adrift.

94. Reaction in Non-elastic Bodies.—The effects of action and reaction are modified largely by elasticity, but never so as to destroy their equality. Hang

two clay balls of equal mass by strings of equal lengths so that they will just touch each other. If one be drawn aside and let fall against the other, both will move forward, but only half as far as the first would had it met no resistance. The gain of momentum by the second is due to the action of the first. It is equal to the loss of momentum by the first, which loss is due to the reaction of the second.

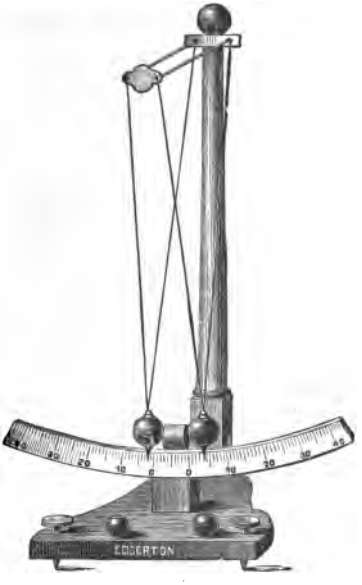


FIG. 16.

95. Reaction in Elastic Bodies. — If two ivory balls, which are elastic, be similarly placed, and the experiment repeated, it will be found that the first ball will give the whole of its motion to the second and remain still after striking, while the second will swing as far as the first would have done if it had met no resistance. In this case, as in the former, it will be seen that the first ball loses just as much momentum as the second gains.

96. Reflected Motion.—*Reflected motion is the motion produced by the reaction of a surface when struck by a body, either the surface, or the body, or both being elastic.*

A ball rebounding from the wall of a house, or from the

cushion of a billiard-table, is an example of reflected motion.

97. Law of Reflected Motion.—The angle included between the direction of the moving body before it strikes the reflecting surface and a perpendicular to that surface drawn from the point of contact, is called the angle

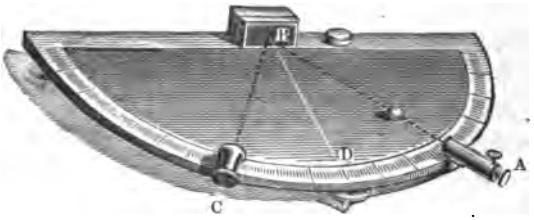


FIG. 17.

of incidence. The angle between the direction of the moving body after striking and the perpendicular, is called the angle of reflection. *The angle of incidence is equal to the angle of reflection, and lies in the same plane.* A ball shot from A will be reflected at B back to C, making the angles ABD and CBD equal.

EXERCISES. (*Answers to be written.*)

1. Represent graphically the resultant of two forces, 100 and 150 pounds respectively, exerted by two men pulling a weight in the same direction. Determine its value.

2. In similar manner, represent the resultant of the same forces when the men pull in opposite directions. Determine its value.

3. Suppose an attempt be made to row a boat at the rate of four miles an hour directly across a stream flowing at the rate of three miles an hour. Determine the direction and velocity of the boat.

4. A ball falls 64 feet from the mast of a moving ship to the deck. During the time of the fall, the ship moved forward 24 ft. Represent the actual path of the ball. Find its length.

5. A sailor climbs a mast at the rate of 3 ft. a second ; the ship is

sailing at the rate of 12 ft. a second. Over what space does he actually move during 20 seconds?

6. A foot-ball simultaneously receives three horizontal blows; one from the north having a force of 10 pounds; one from the east having a force of 15 pounds, and one from the south-east having a force of 804 kinetic units. Determine the direction of its motion. (If the pupil is sure that he has mastered this section, he may determine the momentum of the ball thus kicked.)

7. Why does a cannon recoil or a shot-gun "kick" when fired? Why does not the velocity of the gun equal the velocity of the shot?

8. If the river mentioned in the third problem be one mile wide, how far did the boat move, and how much longer did it take to cross than if the water had been still?

9. A plank 12 feet long has one end on the floor and the other end raised 6 feet. A 50-pound cask is being rolled up the plank. Resolve the gravity of the cask into two components, one perpendicular to the plank to indicate the plank's upward pressure, and one parallel to the plank to indicate the muscular force needed to hold the cask in place. Find the magnitude of this needed muscular force.

Recapitulation.—In this section we have considered Dynamics, Statics, and Kinetics; Force, and its three Elements; the Gravity, Kinetic, and C. G. S. Units of Force; Momentum; Newton's Laws of Motion; Centrifugal Force; Resultant Motion; the Composition and Graphic Representation of forces; Resultant and Equilibrant; Parallelogram, Triangle, and Polygon of forces; Resolution of forces; Reaction and Reflected Motion.

SECTION II.

GRAVITATION.

98. What is Gravitation?—*Every particle of matter in the universe has an attraction for every other particle. This attractive force is called gravitation.*

99. Three Important Facts.—In respect to gravitation, three important facts have been established:

(1.) *It acts instantaneously.* Light and electricity require time to traverse space; not so with this force. If a new star were created in distant space, its light might not reach the earth for hundreds or thousands of years. It might be invisible for many generations to come, but its *pull* would be felt by the earth in less than the twinkling of an eye.

(2.) *It is unaffected by the interposition of any substance.* During an eclipse of the sun, the moon is between the sun and the earth. But at such a time, the sun and earth attract each other with the same force that they do at other times.

(3.) *It is independent of the kind of matter, but depends upon the quantity or mass and the distance.* We must not fall into the error of supposing that mass means size. The planet Jupiter is about 1300 times as large as the earth, but it has only about 300 times as much matter because it is only 0.23 as dense.

100. Laws of Gravitation.—(1.) *Gravitation varies directly as the mass.*

(2.) *Gravitation varies inversely as the square of the distance.*

For example, doubling the mass, doubles the attraction; doubling the distance, quarters the attraction; doubling both the mass and distance will halve the attraction. Trebling the mass will multiply the attraction by three; trebling the distance will divide the attraction by nine; trebling both the mass and distance will divide the attraction by three $\left(\frac{3}{3^2}=\frac{1}{3}\right)$.

101. Equality of Attraction. — *The force exerted by one body upon a second is the same as that exerted by the second upon the first.*

The earth draws the falling apple with a force that gives it a certain momentum; the apple draws the earth with an equal force which gives to it an equal momentum. The momenta are equal; the velocities are not. Why not?

102. Gravity.—The most familiar illustration of gravitation is *the attraction between the earth and bodies upon or near its surface.* This particular form of gravitation is commonly called gravity; its measure is weight; its direction is that of the plumb-line, vertical.

103. Weight.—Weight, like gravity, the force of which it is the measure, *varies directly as the mass, and inversely as the square of the distance.* This distance is to be measured between the centres of gravity of the earth and of the body weighed. When we ascend from the surface there is nothing to interfere with the working of this law; but when we descend from the surface

we leave behind us particles of matter whose attraction partly counterbalances that of the rest of the earth.

104. An Example.—Consider the earth's radius to be 4,000 miles, and the earth's density to be uniform. At the centre, a body, whose weight at the surface is 100 pounds, would be attracted in every direction with equal force. The resultant of these equal and opposite forces would be zero, and the body would have no weight. At 1,000 miles from the centre, one fourth of the distance to the surface, it would weigh 25 pounds, one-fourth the surface weight; at 2,000 miles from the centre, 50 pounds; at 3,000 miles from the centre, 75 pounds; at 4,000 miles from the centre, or the surface distance, it would weigh 100 pounds or the full surface weight. If carried up still further, the weight will decrease according to the square of the distance. At an elevation of 4,000 miles above the surface (8,000 miles from the centre) it will weigh 25 pounds, or one-fourth the surface weight.

105. Law of Weight.—*Bodies weigh most at the surface of the earth. Below the surface, the weight decreases as the distance to the centre decreases. Above the surface, the weight decreases as the square of the distance from the centre increases.*

106. Formulas for Gravity Problems.—Representing the surface weight by W and the surface distance (4,000 miles) by D, the other weight by w, and the other distance from the earth's centre by d, the above law may be algebraically expressed as follows:

Below the earth's surface: $w : W :: d : D$.

Above the earth's surface: $w : W :: D^2 : d^2$.

EXERCISES.

1. How far below the surface of the earth will a ten-pound ball weigh only four pounds?

Solution.

Formula: $w : W :: d : D.$

Substituting: $4 : 10 :: d : 4000$

$10d = 16000$

$d = 1600$ miles from centre.

$4000 - 1600 = 2400$ miles below the surface.—*Ans.*

2. What would a body weighing 550 lbs. on the surface of the earth weigh 3,000 miles below the surface? *Ans.* 137½ lbs.

3. Two bodies attract each other with a certain force when they are 75 *m.* apart. How many times will the attraction be increased when they are 50 *m.* apart? *Ans.* 2¼.

4. Given three balls. The first weighs 6 lbs. and is 25 ft. distant from the third. The second weighs 9 lbs. and is 50 ft. distant from the third. (*a*) Which exerts the greater force upon the third? (*b*) How many times greater? *Ans.* 8/3.

5. A body at the earth's surface weighs 900 pounds; what would it weigh 8,000 miles above the surface?

6. How far above the surface of the earth will a pound avoirdupois weigh only an ounce?

7. At a height of 3,000 miles above the surface of the earth, what would be the difference in the weights of a man weighing 200 lbs. and of a boy weighing 100 lbs.?

8. Find the weight of a 180 lb. ball (*a*) 2,000 miles above the earth's surface; (*b*) 2,000 miles below the surface.

9. (*a*) Would a 50 lb. cannon ball weigh more 1,000 miles above the earth's surface, or 1,000 miles below it? (*b*) How much?

10. If the moon were moved to three times its present distance from the earth, what would be the effect (*a*) on its attraction for the earth? (*b*) On the earth's attraction for it?

11. How far below the surface of the earth must an avoirdupois pound weight be placed in order to weigh one ounce?

12. How far above the surface of the earth must 2,700 pounds be placed to weigh 1,200 pounds? *Ans.* 2,000 miles.

107. Centre of Gravity.—*The centre of gravity of a body is the point about which all the matter composing the body may be balanced.*

The force of gravity tends to draw every particle of matter toward the centre of the earth, or downward in a vertical line. We may therefore consider the effect of this force upon any body as the *sum* of an almost infinite number of parallel forces, each of which is acting upon one of the molecules of which that body is composed. We may also consider this sum of forces, or total gravity, as acting upon a single point, just as the force exerted by two horses harnessed to a whiffle-tree is equivalent to another force (resultant) equal to the sum of the forces exerted by the horses, and applied at a single point at or near the middle of the whiffle-tree. This single point, which may thus be regarded as the point of application of the force of gravity acting upon a body, is called the centre of gravity of that body. In other words, the weight of a body may be considered as concentrated at the centre of gravity.

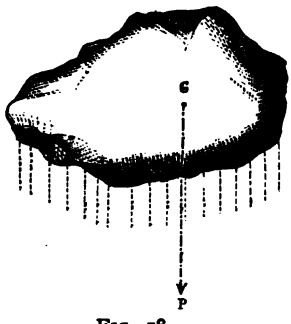


FIG. 18.

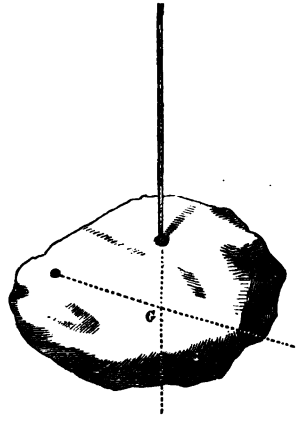


FIG. 19.

108. How to find the Centre of Gravity. — In a freely moving body, the centre of gravity will be brought as low as possible, and will, therefore, lie in a vertical line drawn through the point of

support. This fact affords a ready means of determining the centre of gravity experimentally.

Let any irregularly shaped body, as a stone or chair, be suspended so as to move freely. Drop a plumb-line from the point of suspension, and make it fast or mark its direction. The centre of gravity will lie in this line. From a second point, not in the line already determined, suspend the body; let fall a plumb-line as before. The centre of gravity will lie in this line also. But to lie in both lines, the centre of gravity must lie at their intersection. (Fig. 19.)

109. May be Outside of the Body.—The centre of gravity may be outside of the matter of which a body consists, as in the case of a ring, hollow sphere, box, or cask. The same fact is illustrated by the "balancer," represented in the figure. The centre of gravity is in the line joining the two heavy balls, and thus under the foot of the waltzing figure. But the point wherever found will have the same properties as if it lay in the mass of the body. In a freely falling body, no matter how irregular its form, or how indescribable the curves made by any of its projecting parts, the line of direction in which the centre of gravity or point of application moves will be a vertical line (§ 65 [2]).

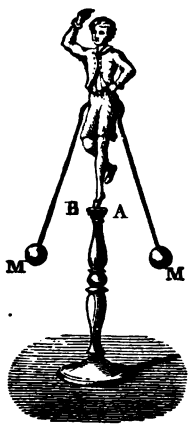


FIG. 20.

110. Equilibrium.—Inasmuch as the centre of gravity is the point at which the weight of a body is concentrated, *when the centre of gravity is supported, the whole body will*

rest in a state of equilibrium. The centre of gravity will be supported when it coincides with the point of support, or is in the same vertical line with it.

111. Stable Equilibrium.—*A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to return to that position, is said to be in stable equilibrium.* Such a displacement raises the centre of gravity. Examples: a disc supported above the centre; a semi-spherical oil-can; a right cone placed upon its base; a pendulum or plumb-line. The cavalry-man represented in Fig. 21, is in stable equilibrium, and may rock up and down, balanced upon his horse's hind-feet, because the heavy ball brings the centre of gravity of the combined mass below the points of support. The "balancer" (Fig. 20) affords another example of stable equilibrium.

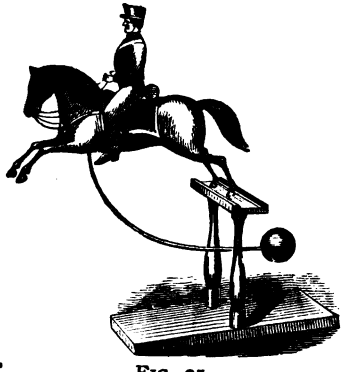


FIG. 21.

112. Unstable Equilibrium.—*A body supported in such a way that, when slightly displaced from its position of equilibrium, it tends to fall further from that position, is said to be in unstable equilibrium.* Such a displacement lowers the centre of gravity. The body will not come to rest until the centre of gravity has reached the lowest possible point, when it will be in stable equilibrium. Examples: A disc sup-

ported below its centre; a right cone placed on its apex; an egg standing on its end; or a stick balanced upright upon the finger.

113. Neutral Equilibrium.—*A body supported in such a way that, when displaced from its position of equilibrium, it tends neither to return to its former position nor to fall further from it, is said to be in neutral or indifferent equilibrium.* Such a displacement neither raises nor lowers the centre of gravity. Examples: A disc supported at its centre; a sphere resting on a horizontal surface; a right cone resting on its side.

(*a.*) In the accompanying figure M, N and O represent three cones placed respectively in these three conditions of equilibrium. The letter *g* shows the position of the centre of gravity in each. If a body have two or more points of support lying in the same straight line, the body will be in neutral, stable or unstable equilibrium according as the centre of gravity lies in this line, is directly below it or above it.

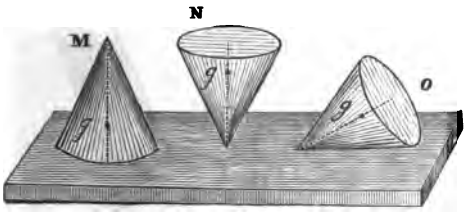


FIG. 22.

114. Line of Direction.—*A vertical line drawn downward from the centre of gravity is called the line of direction.* As we have seen, it represents the direction in which the centre of gravity would move if the body were unsupported. It may be considered as a line connecting the centre of gravity of the given body and the centre of the earth.

115. The Base.—*The side on which a body rests is called its base.* If the body be supported on

legs, as a chair, the base is the polygon formed by joining the points of support.

116. Stability.—*When the line of direction falls within the base, the body stands; when without the base, the body falls.*

In the case of the tower represented in Fig. 23, if the upper part be removed, the line of direction will be as shown by the left hand dotted line. It falls within the base, and the tower stands. When the upper part is fastened to the tower, the line of direction is represented by the right hand dotted line. This falls without the base, and the tower falls. The stability of bodies is measured by the amount of work necessary to overturn them. This depends upon the distance that it is necessary to raise the centre of gravity (equivalent to raising the whole body), that the line of direction may fall without the base. When the body rests upon a point, as does the sphere, or upon a line, as does the cylinder, a very slight force is sufficient to move it, no elevation of the centre of gravity being necessary. The broader the base, and the lower the centre of gravity, the greater the stability.

FIG. 23.

117. Illustrations of Stability.—Let the figure represent the vertical section of a brick placed upon its side, its position of greatest stability. In order to stand the brick upon its end, g, the centre of gravity must pass over the edge c. That is to

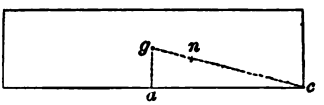


FIG. 24.

say, the centre of gravity must be raised a distance equal to the difference between *ga* and *gc*, or the distance *nc*. But to lift *g* this distance is the same as to lift the whole brick vertically a distance equal to *nc*. Now draw similar figures for the brick when placed upon its edge and upon its end. In each case make *gn* equal to *ga*, and see that the value of *nc* decreases. But *nc* represents the distance that the brick, or its centre of gravity, must be raised before the line of direction can fall without the base, and the body be overturned. To lift the brick, or its centre of gravity, a small distance involves less work than to lift it a greater distance. Therefore, the greater the value of *nc*, the more work required to overturn the body, or the greater its stability. But this greater value of *nc* evidently depends upon a larger base, a lower position for the centre of gravity, or both.

FIG. 25.

(*a.*) These facts explain the stability of leaning towers like those of Pisa and Bologna. In some such towers the centre of gravity is lowered by using heavy materials for the lower part and light materials for the upper part of the structure. It is difficult to stand upon one foot or to walk upon a tight rope because of the smallness

of the base. A porter carrying a pack is obliged to lean forward; a man carrying a load in one hand is obliged to lean away from the load, to keep the common centre of gravity of man and load over the base formed by joining the extremities of his feet. Why does a person stand less firmly when his feet are parallel and close together than when they are more gracefully placed? Why can a child walk more easily with a cane than without? Why will a book placed on a desk-lid stay there while a marble would roll off? Why is a ton of stone on a wagon less likely to upset than a ton of hay similarly placed?

EXERCISES.

Explanatory Note.—The first problem in the table below may be read as follows: What will be the weight of a body which weighs 1200 pounds at the surface of the earth, when placed 2000 miles below the surface? When placed 4000 miles above the surface? (Radius of earth=4000 miles.) All of the measurements are from the surface.

Number of Problem.	Below Surface.		At Surface.	Above Surface.	
	Pounds.	Miles from Surface.	Pounds.	Pounds.	Miles from Surface.
1	?	2000	1200	?	4000
2	300	?	1200	533⅓	?
3	?	3000	800	?	6000
4	?	1000	150	?	1000
5	100	?	400	100	?
6	250	3000	?	?	4000
7	?	1600	?	32	6000
8	12½	?	100	25	?
9	?	3250	480	?	2000
10	90	?	450	50	?
11	160	?	256	?	12000
12	201.6	2600	?	16	?
13	256	?	?	40.96	16000
14	20250	?	324000	9000	?
15	?	3200	?	1280	9000

Recapitulation.—In this section we have considered Gravitation; Facts concerning it; its Law; Gravity; Weight; Law of Weight; Centre of Gravity; Equilibrium and Stability of Bodies.

SECTION III.

FALLING BODIES.

118. A Constant Force.—The tendency of force is generally to produce motion. Acting on a given mass for a given time, a given force will produce a certain velocity. If the same force acts on the same mass for twice the time it will produce a double velocity. *A force which thus continues to act uniformly upon a body, even after the body has begun to move, is called a constant force.* The velocity thus produced is called a uniformly accelerated velocity. If a constant force gives a body a velocity of 10 feet in one second, it will give a velocity of 20 feet in two seconds, of 30 feet in three seconds, and so on. The force of gravity is a constant force and the velocity it imparts to the falling body is a uniformly accelerated velocity.

119. Velocities of Falling Bodies.—If a feather and a cent be dropped from the same height, the cent will reach the ground first. This is not because the cent is heavier, but because the feather meets with more resistance from the air. If this resistance can be removed or equalized, they will fall equal distances in equal times,

or will fall with the same velocity. This resistance may be avoided by trying the experiment in a glass tube from which the air has been removed. The resistance may be equalized by making the two falling bodies of the same size and shape but of different weights. Take an iron and a wooden ball of the same size, drop them at the same time from an upper window, and notice that they will strike the ground at sensibly the same time.

FIG. 26.

120. Reason of this Equality.—The cent is heavier than the feather and is therefore acted upon by a greater force. The iron ball has the greater weight, which shows that it is acted upon by a greater force than the wooden ball. But this greater force has to move a greater mass, has to do more work than the lesser force. *For the greater force to do the greater work requires as much time as for the lesser force to do the lesser work.* The working force and the work to be done increase in the same ratio. A regiment will march a mile in no less time than a single soldier would do it; a thousand molecules can fall no further in a second than a single molecule can.

121. Galileo's Device.—To avoid the necessity for great heights, and the interference of rapid motion with accurate observations, Galileo used an inclined

plane, consisting of a long ruler having a grooved edge, down which a heavy ball was made to roll. In this way he reduced the velocity, and diminished the interfering resistance of the atmosphere without otherwise changing the nature of the motion. Let AB represent a plane so inclined that the velocity of a body rolling from B toward A will be readily observable. Let C be a heavy ball. The gravity of the ball may be represented by the vertical line CD. But CD may be resolved into CF, which represents a force acting perpendicular to the plane and producing pressure upon it but no motion at all, and CE, which represents a force acting parallel to the plane, the only force of any effect in producing motion. It may be shown geometrically that

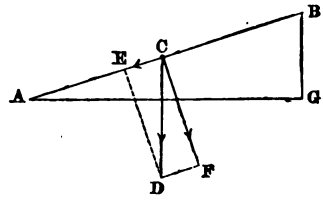


FIG. 27.

EC : CD :: BG : BA. (*Olney's Geometry*, Art. 341.)

By reducing, therefore, the inclination of the plane we may reduce the magnitude of the motion producing component of the force of gravity and thus reduce the velocity. This will not affect the laws of the motion, that motion being changed only in amount, not at all in character.

122. Attwood's Device. —For the purpose of lessening the velocity of falling bodies without changing the character of the motion, Mr. Attwood devised a machine which has

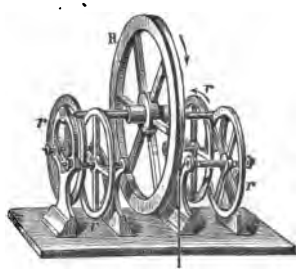
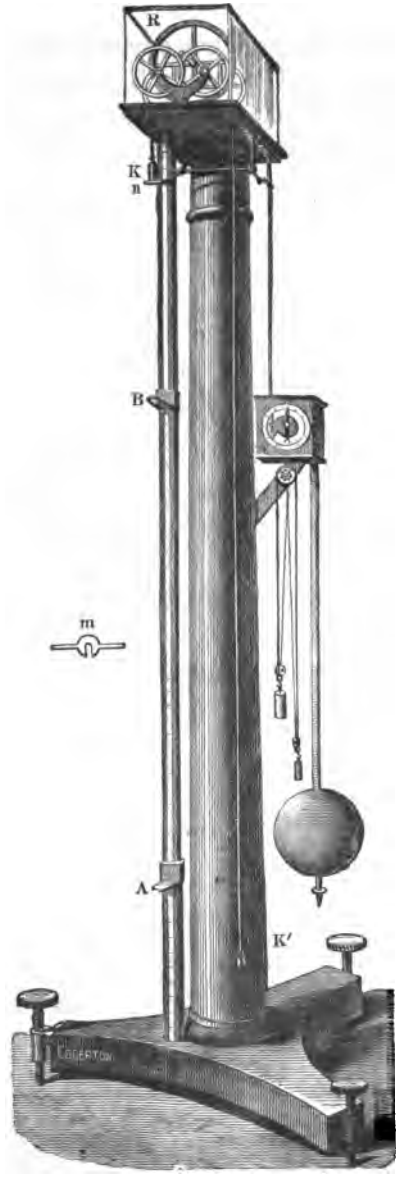


FIG. 28.



taken his name. Attwood's machine consists essentially of a wheel R, about six inches in diameter, over the grooved edge of which are balanced two equal weights, suspended by a long silk thread, which is both light and strong. The axle of this wheel is supported upon the circumferences of four friction wheels, *r*, *r*, *r*, *r*, for greater delicacy of motion. As the thread is so light that its weight may be disregarded, it is evident that the weights will be in equilibrium whatever their position.

This apparatus is supported upon a wooden pillar, seven or eight feet high. The silk cord carrying K, one of the weights, passes in front of a graduated rod which carries a movable ring B, and a movable platform A. At the top of the pillar is a plate *n*,

which may be fastened in a horizontal position for the support of K at the top of the graduated rod. This plate may also be dropped to a vertical position, thus allowing K, when loaded, to fall. A clock, with a pendulum beating seconds, serves for the measurement of time, and the dropping of the plate at the top of the pillar. A weight or rider, *m*, is to be placed upon K, and give it a downward motion. Levelling screws are provided by means of which the graduated rod may be made vertical, and K be made to pass through the middle of B.

(*a*.) Suppose that K and K′ weigh 315 grams each, and that the rider *m* weighs 10 grams. When *m* is placed upon K and the plate dropped by the action of the clock, the gravity of *m* causes the weights to move. We now have the motion of 640 grams produced by the gravity of only 10 grams. When this force (gravity) moves only 10 grams it will give it a certain velocity. When the same force moves 640 grams it has to do 64 times as much work, and can do it with only $\frac{1}{64}$ the velocity. In this way we are able to give to K and *m* any velocity of fall that we desire.

123. Experiments.—Arrange the apparatus by supporting K and *m* upon the shelf *n*. As the hand of the clock passes a certain point on the dial, 12 for example, the shelf *n* is dropped and the weights begin to move. By a few trials, B may be so placed that at the end of one second it will lift *m* from K, and thus show how far the weights fall in one second. Other experiments will show how many such spaces they will fall in the next second or in two seconds; in the third second or in three seconds; in the fourth second or in four seconds, etc.

Suppose that B lifts off *m* at the end of the first second. The moving force being no longer at work, inertia will keep K moving with the same velocity that it had at the end of the first second. By placing A so that K will reach it at the end of the second second, the distance AB will

indicate the velocity with which K was moving when it passed B at the end of the first second. In a similar way the velocity at the end of the second, third, or fourth second may be found.

124. Results.—Whatever the space passed over in the first second by the weights or the ball, it will be found that there is an uniform increase of velocity. Galileo found that if the plane was so inclined that the ball would roll one foot during the first second, it would roll three feet during the next second, five feet during the third, and so on, the common difference being two feet, or twice the distance traversed in the first second.

He found that under the circumstances supposed, the ball would have a velocity of two feet at the end of the first second, of four feet at the end of the next, of six feet at the end of the third, and so on, the increase of velocity during the first second being the same as the increase during any subsequent second.

He found that, under the circumstances supposed, the ball would pass over one foot during one second, four feet during two seconds, and nine feet during three seconds, and so on. Similar results may be obtained with Attwood's machine.

125. Table of Results.—These results are generalized in the following table, in which t represents any given number of seconds:

Number of Seconds.	*Spaces fallen during each Second.*	*Velocities at the End of each Second.*	*Total Number of Spaces fallen.*
1	1	2	1
2	3	4	4
3	5	6	9
4	7	8	16
etc.	etc.	etc.	etc.
t	$2t-1$	$2t$	t^2

126. Unimpeded Fall.—By transferring matter from K′ to K, the velocity with which the weights move will be increased. When all of K′ has been transferred to K, *the weights will fall, in this latitude, 16.08 ft. or 4.9 m. during the first second.*

If the plane be given a greater inclination, the ball will, of course, roll more rapidly and our unit of space will increase from one foot, as supposed thus far, to two, three, four or five feet, and so on, but the *number* of such spaces will remain as indicated in the table above. By disregarding the resistance of the air, we may say that when the plane becomes vertical, the body becomes a freely falling body. Our unit of space has now become 16.08 ft. or 4.9 *m.* It will fall this distance during the first second, three times this distance during the next second, five times this distance during the third second, and so on.

127. Increment of Gravity.—*During the first second the freely falling body will gain a velocity of 32.16 feet.* It will make a like gain of velocity during each subsequent second of its fall. This distance is therefore called the increment of velocity due to gravity, and is generally represented by $g = 32.16$ ft. or 9.8 *m.*

Note—This value must not be forgotten.

128. Formulas for Falling Bodies.—If now we represent our space by $\frac{1}{2}g$, the velocity at the end of any second by v, the number of seconds by t, the spaces fallen each second by s, and the total space fallen through by S, we shall have the following formulas for freely falling bodies :

(1.) $v = gt \ (= \frac{1}{2}g \times 2t)$.

(2.) $s = \frac{1}{2}g \ (2t - 1)$.

(3.) $S = \frac{1}{2}g \ t^2$.

129. Laws of Falling Bodies.—These formulas may be translated into ordinary language as follows:

(1.) The velocity of a freely falling body at the end of any second of its descent is equal to 32.16 ft. multiplied by the number of the second.

(2.) The distance traversed by a freely falling body during any second of its descent is equal to 16.08 ft. multiplied by one less than twice the number of seconds.

(3.) The distance traversed by a freely falling body during any number of seconds is equal to 16.08 ft. multiplied by the square of the number of seconds.

130. For Bodies Rolling Down an Inclined Plane.—If the body be rolling down an inclined plane instead of freely falling, of course the increment of velocity will be less than 32.16 ft. The formulas above given may be made applicable by multiplying the value of g by the ratio between the height and length of the plane.

131. Initial Velocity of Falling Bodies.—We have been considering bodies falling from a state of rest, gravity being the only force that produced the motion. But a body may be thrown downward as well as dropped. In such a case, the effect of the throw must be added to the effect of gravity. It becomes an illustration of the first case under Composition of Forces (§ 80), the resultant being the sum of the components. If a body be thrown downward with an initial velocity of fifty feet per second, the formulas will become $v = gt + 50$; $s = \frac{1}{2}g\ (2t - 1) + 50$; $S = \frac{1}{2}gt^2 + 50t$.

132. Ascending Bodies.—In the consideration of ascending bodies we have the direct opposite of the laws of falling bodies. When a body is thrown downward, gravity

increases its velocity every second by the quantity g. When a body is thrown upward, gravity diminishes its velocity every second by the same quantity. Hence the time of its ascent will be found by dividing its initial velocity by g. *The initial velocity of a body that can rise against the force of gravity for a given number of seconds is the same as the final velocity of a body that has been falling for the same number of seconds.*

(*a.*) The spaces traversed and the velocities attained during successive seconds will be the same in the ascent, only reversed in order. If a body be shot upward with a velocity of 321.6 feet, it will rise for ten seconds, when it will fall for ten seconds. The tenth second of its ascent will correspond to the first of its descent, *i. e.*, the space traversed during these two seconds will be the same; the eighth second of the ascent will correspond to the third of its descent; the end of the eighth second of its ascent will correspond to the end of the second second of its descent.

133. Projectiles.—Every projectile is acted upon by three forces:

(1.) The impulsive force, whatever it may be.

(2.) The force of gravity.

(3.) The resistance of the air.

134. Random or Range.—*The horizontal distance from the starting-point of a projectile to where it strikes the ground is called its random or range.* In Fig. 30, the line GE represents the random of a projectile starting from F, and striking the ground at E.

135. Path of a Projectile.—The path of a projectile is a curve, the resultant of the three forces above mentioned. Suppose a ball to be thrown horizontally. Its impulsive force will give a uniform velocity, and may

be represented by a horizontal line divided into equal parts, each part representing a space equal to the velocity. The force of gravity may be represented by a vertical line divided into unequal parts, representing the spaces 1, 3, 5, 7, etc., over which gravity would move it in successive seconds. Constructing the parallelograms of forces, we find that at the end of the first second the ball will be at A, at the end of the next second at B, at the end of the third at C, at the end of the fourth at D, etc. The resultant of these two forces is a curve called a parabola. It will be seen that, in a case like this, the range GE may be found by multiplying the velocity by the number of seconds it will take the body to fall from F to G. The resistance of the air modifies the nature of the curve somewhat.

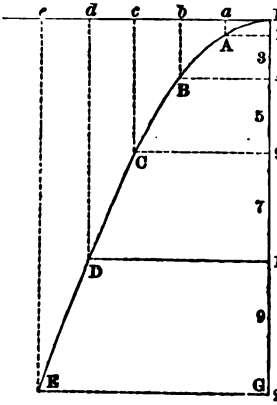


FIG. 30.

136. Time of a Projectile.—From the second law of motion, it follows that the ball shot horizontally will reach the level ground in the same time as if it had been dropped; that the ball shot obliquely upward from a horizontal plain will reach the ground in twice the time required to fall from the highest point reached. These statements may be easily verified by experiment.

Exercises.

1. What will be the velocity of a body after it has fallen 4 seconds?

Solution:
$$v = gt.$$
$$v = 32.08 \times 4.$$
$$v = 128.32. \qquad \textit{Ans.}\ 128.32 \text{ ft.}$$

2. A body falls for several seconds; during one it passes over 530.64 feet; which one is it?

Solution:
$$s = \tfrac{1}{2}g\,(2t - 1).$$
$$530.64 = 16.08 \times (2t - 1).$$
$$33 = 2t - 1.$$
$$34 = 2t.$$
$$17 = t. \qquad \textit{Ans.}\ 17\text{th second.}$$

3. A body was projected vertically upward with a velocity = 96.48 feet; how high did it rise?

Solution:
$$v = gt. \quad \text{(See § 132.)}$$
$$96.48 = 32.16t.$$
$$3 = t.$$
$$S = \tfrac{1}{2}gt^2.$$
$$S = 16.08 \times 9.$$
$$S = 144.72. \qquad \textit{Ans.}\ 144.72 \text{ ft.}$$

4. How far will a body fall during the third second of its fall?

5. How far will a body fall in 10 seconds? *Ans.* 1608 ft.

6. How far in $\frac{1}{4}$ second? *Ans.* 4.02 ft.

7. How far will a body fall during the first one and a half seconds of its fall?

8. How far in $12\frac{1}{2}$ seconds?

9. A body passed over 787.92 feet during its fall; what was the time required? *Ans.* 7 sec.

10. What velocity did it finally obtain?

11. A body fell during $15\frac{1}{2}$ seconds; give its final velocity.

12. In an Attwood's machine the weights carried by the thread are $6\frac{1}{4}$ ounces each. The friction is equivalent to a weight of two ounces. When the "rider," which weighs one ounce, is in position, what will be its gain in velocity per second?

13. A stone is thrown horizontally from the top of a tower 257.28 ft. high with a velocity of 60 ft. a second. Where will it strike the ground?

14. A body falls freely for 6 seconds. What is the space traversed during the last 2 seconds of its fall?

15. A body is thrown directly upward with a velocity of 80.4 ft. (*a*) What will be its velocity at the end of 3 seconds, and (*b*) in what direction will it be moving?

16. In Fig. 30, what is represented by the following lines: F1? Fa? Aa? Fc? Dd?

17. A body falls 357.28 ft. in 4 seconds. What was its initial velocity?

18. A ball thrown downward with a velocity of 35 ft. per second reaches the earth in 12½ seconds. (*a*) How far has it moved, and (*b*) what is its final velocity?

19. (*a*) How long will a ball projected upward with a velocity of 3,216 ft. continue to rise? (*b*) What will be its velocity at the end of the fourth second? (*c*) At the end of the seventh?

20. A ball is shot from a gun with a horizontal velocity of 1,000 feet, at such an angle that the highest point in its flight = 257.28 feet. What is its random? *Ans.* 8000 ft.

21. A body was projected vertically downward with a velocity of 10 feet; it was 5 seconds falling. Required the entire space passed over. *Ans.* 452 ft.

22. Required the final velocity of the same body. *Ans.* 170.8 ft.

23. A body was 5 seconds rolling down an inclined plane and passed over 7 feet during the first second. (*a*) Give the entire space passed over, and (*b*) the final velocity.

24. A body rolling down an inclined plane has at the end of the first second a velocity of 20 feet; (*a*) what space would it pass over in 10 seconds? (*b*) If the height of the plane was 800 ft., what was its length? *Last Ans.* 1286.4 ft.

25. A body was projected vertically upward and rose 1302.48 feet; give (*a*) the time required for its ascent, (*b*) also the initial velocity.

26. A body projected vertically downward has at the end of the seventh second a velocity of 515.12 feet; how many feet will it have passed over during the first 4 seconds? *Ans.* 297.28 ft.

27. A body falls from a certain height; 3 seconds after it has started, another body falls from the height of 787.92 feet; from what height must the first fall if both are to reach the ground at the same instant? *Ans.* 1608 ft.

Recapitulation.—In this section we have considered the Nature of a Constant Force; the Fact that all Substances fall equal Distances in equal Times; the

Explanation of this; the Practical Difficulties in studying the Laws of Falling Bodies; Galileo's Device for obviating those Difficulties; Attwood's Device; the Increment of Gravity; Formulas and Laws for Falling Bodies; the Case of Falling Bodies having an Initial Velocity; Ascending Bodies; Projectiles; their Random; their Paths; their Time of Flight.

SECTION IV.

THE PENDULUM.

137. The Simple Pendulum.—A simple pendulum is conceived as *a single material particle supported by a line without weight, capable of oscillating about a fixed point.* Such a pendulum has a theoretical but not an actual existence, and has been conceived for the purpose of arriving at the laws of the compound pendulum.

138. The Compound Pendulum.—A compound or physical pendulum is *a weight so suspended as to be capable of oscillating about a fixed point.* The compound pendulum appears in many forms. The most common form consists of a steel rod, thin and flexible at the top, carrying at the bottom a heavy mass of metal known as the *bob.* The bob is sometimes spherical but generally lenticular, as this form is less subject to resistance from the air.

139. Motion of the Pendulum.—When the supporting thread or bar is vertical, the centre of gravity is in the lowest possible position, and the pendulum remains at rest, for the force of gravity tends to draw it downward producing pressure at the point of support, but no motion. But when the pendulum is drawn from its vertical position, the force of gravity, MG, is resolved (§ 91) into two components, one of which, MC, produces pressure at the point of support, while the other, MH, acts at right angles to it, producing motion. Gravity therefore draws it to a vertical position, when inertia carries it beyond until it is stopped and drawn back again by gravity. It thus swings to and fro in an arc, MNO.

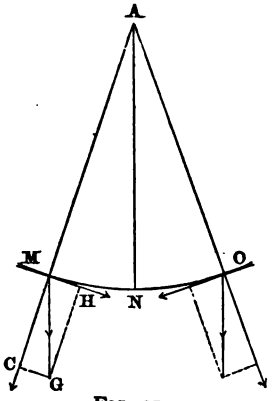


FIG. 31.

140. Definitions.—The motion from one extremity of this arc to the other is called a vibration or oscillation. The time occupied in moving over this arc is called the time of vibration or oscillation. The angle measured by this arc is called the amplitude of vibration. The trip from M to O is a vibration; the angle MAO is the amplitude of vibration.

141. Centre of Oscillation.—A short pendulum vibrates more rapidly than a long pendulum; this is a familiar fact. It is evident, then, that in every pendulum (not simple) the parts nearest the centre of suspension tend to move faster than those further away, and force them to

move more rapidly than they otherwise would. On the other hand, the parts furthest from the centre of suspension tend to move more slowly than those nearer, and force these to retard their individual rates of motion. Between these there will be a particle moving, of its own accord, at the average rate of all. The accelerating tendency of the particles above it is compensated by the retarding tendency of the particles below it. *This molecule, therefore, will move as if it were vibrating alone, supported by a thread without weight.* It fulfills all the conditions of a simple pendulum. This point is called the *centre of oscillation.*

142. The Real Length of a Pendulum.—The laws of the simple pendulum are applicable to the compound pendulum if we consider the length of the latter to be the length of the equivalent simple pendulum, *i. e.*, *the distance between the centres of suspension and oscillation.* We, therefore, may say that the *real* length of a pendulum is the distance between the centre of suspension and the centre of oscillation. The real length is less than the apparent length except in the imaginary case of the simple pendulum.

143. First Law of the Pendulum.—*The vibrations of a given pendulum, at any given place, are isochronous, i. e.,* are performed in equal times, whether the arc be long or short. Each pupil should satisfy himself of the truth of this proposition, by the only true scientific method, experiment.

144. The Cycloidal Pendulum. — *The law above given is strictly true only when the pendu-*

lum vibrates in a cycloidal arc. A cycloid is the curve traced by a point in the circumference of a circle rolling along a straight line. The pendulum may be made to move in such an arc by suspending a small heavy ball by a thread between two cheeks upon which the thread winds as the pendulum vibrates. The cheeks must be the two halves of a cycloid; each cheek must have the same length as the thread. The path of the ball will be a cycloid, identical with that to which the cheeks belong.

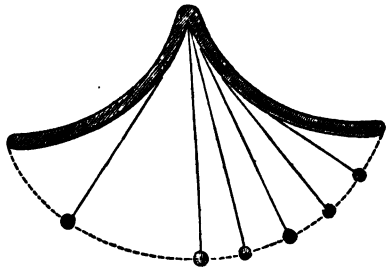


FIG. 32.

(*a.*) The cycloidal pendulum is of little practical use. If the amplitude of an ordinary pendulum does not exceed five degrees, the *circular arc*, thus described, will not vary much from the true cycloidal arc, and the pendulum will be practically isochronous. If from the centre of suspension, with radius equal to the length of the string, a circular arc be described, the two curves will sensibly coincide for at least five degrees. This is why the pendulums of "regulator" clocks have a small swing or amplitude.

145. Second Law of the Pendulum.—*The time of vibration is independent of the weight or material of the pendulum,* depending only upon the length of the pendulum, and the intensity of the force of gravity at any given place.

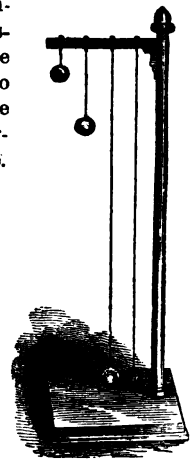


FIG. 33.

(*a.*) Each pupil should try the experiment, *at home*, with balls of equal size but different

weight. The investment of a little time and ingenuity in simple experiments will pay large dividends.

146. Third Law of the Pendulum.—The vibrations of pendulums of different lengths are performed in different times. *The lengths are directly proportional to the squares of the times of vibration, or inversely proportional to the squares of the numbers of vibrations in a given time.*

Note.—Be careful to distinguish clearly between the expressions "times of vibration" and "numbers of vibration." The greater the *time*, the less the *number*. You may easily verify by experiment the three laws already given for the pendulum.

147. The Second's Pendulum. At the equator, *the length of a second's pendulum, at the level of the sea, is 39 inches;* near the poles, 39.2; *in this latitude about 39.1 inches or 993.3 mm.* As such a pendulum would be inconveniently long, use is generally made of one one-fourth as long, which, consequently, vibrates half seconds. The length and time of vibration of this pendulum being thus known, the length of any other pendulum may be found when the time of vibration is given; or the time of vibration may be found when the length is given. The third law is applicable to such a problem.

FIG. 34.

148. Use of the Pendulum in Time-pieces.—The motion of a clock is due to the force of gravity acting upon the weights, or to the elastic-

ity of the spring. But the weights have a tendency toward accelerated motion (falling bodies), while the spring would give an example of diminishing motion. Either defect would be fatal in a time-piece. Hence the properties of the pendulum set forth in the first and third laws are used to *regulate* this motion and make it available for the desired end. If the clock gains time, the pendulum is lengthened by lowering the bob; if it loses time, the pendulum is shortened by raising the bob.

149. Compensation Pendulums.—The expansion of metals by heat is a familiar fact. Hence the tendency of a clock to lose time in summer and to gain time in winter. One plan for counteracting this tendency is by the use of the "gridiron" pendulum which is made of two substances in such a manner that the downward expansion of one will be exactly compensated by the upward expansion of the other. In the figure, the heavy single lines represent steel rods, the effect of whose expansion will be to lower the bob. The light double lines represent brass rods, the effect of whose expansion will be to raise the bob. The steel rod to which the bob is directly attached passes easily through holes in the two horizontal bars which carry the brass uprights. As brass expands more than steel, for a given increase of temperature, it will be seen that these two expansions may be made to neutralize one another.

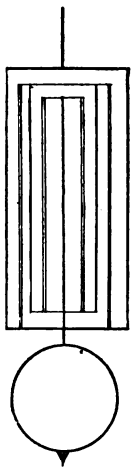


FIG. 35.

EXERCISES.

No.	INCHES.	NUMBER.	TIME.	No.	CM.	NUMBER.	TIME.
1	?	20 per min.	?	11	99.33	?	?
2	?	30 "	?	12	?	?	2 sec.
3	30	?	?	13	?	?	2 min.
4	16	?	?	14	24.83	?	?
5	?	?	¼ sec.	15	?	8 per sec.	?
6	?	?	¼ min.	16	397.32	?	?
7	39.37	? per min.	?	17	11.03	?	?
8	?	10 "	?	18	?	?	10 sec.
9	10	? per sec.	?	19	2483.25	?	?
10	?	1 per min.	?	20	?	?	4 sec.

21. How will the times of vibration of two pendulums compare, their lengths being 4 feet and 49 feet respectively? *Ans.* As 2 to 7.

22. Of two pendulums, one makes 70 vibrations a minute, the other 80 vibrations during the same time; how do their lengths compare? *Ans.* As 49 to 64.

23. If one pendulum is 4 times as long as another, what will be their relative times of vibration?

24. The length of a second's pendulum being 39.1 inches, what must be the length of a pendulum to vibrate in ¼ second?

25. How long must a pendulum be to vibrate once in 3 seconds? In ¼ second?

26. How long must a pendulum be to vibrate once in 3½ seconds?

27. Find the length of a pendulum that will vibrate 5 times in 4 seconds? *Ans.* 25.02 + inches.

28. A pendulum 5 feet long makes 400 vibrations during a certain time; how many vibrations will it make in the same time after the pendulum rod has expanded half an inch?

Recapitulation.—In this section we have considered the Simple Pendulum; the Compound Pendulum; the nature of the Motion of the Pendulum and its Cause; the meaning of the terms Vibration, Time of Vibration, Amplitude of Vibration; Centre of Oscillation; Real Length

of a Pendulum; Laws and Formulas for the Pendulum; the Cycloidal Pendulum; the Second's Pendulum; the Use of the Pendulum in Clock-work; Compensation Pendulums.

SECTION V.

ENERGY.

150. Work.—This is a world of work, a world in which the necessity of working is imposed upon every living creature. If a man is poor, he must work for the means of living; if he is rich, still he must work to live. But in physical science, the term *work* has a broader meaning, and *signifies the overcoming of resistance* of any kind. Whether this overcoming of resistance is pleasant or not does not enter into consideration here, all *play* being a species of *work*. The word is here used in this enlarged, technical sense.

151. Energy.—Energy *is the power of doing work.* If one man can do more work than another, he has more energy. If a horse can do more work, in a given time, than a man, the horse has more energy than the man. If a steam-engine can do more work than a horse, it has more energy. If a moving cannon-ball can overcome a greater resistance than a base-ball it has more energy.

152. Elements of Work Measure.—Imagine a flight of stairs, each step having a rise of twelve inches. On the floor at the foot of the stairs are two weights, of

one and ten pounds respectively. Lift the first weight to the top of the first step. How much work have you performed? Perhaps you will answer, one pound of work. Now place the second weight beside the first. How much work did you perform in so doing? Perhaps you will say ten times as much as before, or ten pounds. Now lift each of them another step, and then another, until they rest on the top of the tenth step. To lift the heavier weight the second, third, and subsequent times involved each as much work as to lift it the first foot, but you would hardly say that you had lifted a hundred pounds. Still it *is* sure that to place it on the tenth step required just ten times as much work as it did to place it on the first step, or just one hundred times as much work as it did to place the one pound weight on the first step. Moreover, it is evident that *the two elements of weight and height are necessarily to be considered* in measuring the work actually performed.

153. Units of Work; the Foot-pound.—It is often necessary to represent work numerically; hence the necessity for a unit of measurement. The unit commonly in use, for the present, in England and this country is the *foot-pound.* A foot-pound is *the amount of work required to raise one pound one foot high* against the force of gravity. The work required to raise one kilogram one meter high against the same force is called a *kilogram-meter.*

(*a.*) To get a numerical estimate of work, we multiply the number of weight units raised by the number of linear units in the vertical height through which the body is raised. A weight of 25 pounds, raised 3 feet, or one of 3 pounds raised 25 feet, represents 75 *foot-pounds.* A weight of 15 *Kg.* raised 10 *m.*, represents 150 *kilogram-meters.*

154. The Erg.—The C. G. S. unit of work is *the work done by a force of one dyne* (§ 69) *working through a distance of one centimeter.* It is called the erg; the term is not yet much used in this country.

155. Horse-Power.—*A horse-power represents the ability to perform 33,000 foot-pounds in a minute.* An engine that can do 66,000 foot-pounds in a minute or 33,000 foot-pounds in half a minute is called a two horse-power engine. To compute the number of horse-powers represented by an engine at work, multiply the number of pounds raised by the number of feet, and divide the product by 33,000 times the number of minutes required to do the work.

Note.—Let the pupil make a *formula* for horse-power, similar to those given for falling bodies.

156. Relation of Velocity to Energy.—Any moving body can overcome resistance, can perform work, has energy. We must acquire the ability to measure this energy. In the first place, we may notice that the *direction* of the motion is unimportant. A body of given weight and velocity can at any instant do as much work when going in one direction as when going in another, when moving horizontally as when moving vertically upward or downward. This energy may be expended in penetrating an earth-bank, knocking down a wall or *lifting itself against the force of gravity.* Whatever be the work actually done, it is clear that the manner of expenditure does not change the amount of energy expended. *We may therefore find to what vertical height the given velocity would lift the body, and thus easily determine its energy in foot-pounds, or kilogram-meters.*

157. An Easier Method.—If we can obtain the same result without the trouble of finding how high the given velocity could raise it, it is generally desirable to do so. Be it remembered that the two elements of our measure are units of weight and units of height. The first of these is given; for the second we may substitute its equivalent in terms of the velocity which also is given. The determination of this equivalent is our present problem. We must use our knowledge of the laws of falling bodies. Our vertical height is the whole space passed over by an ascending body (§ 132). We have given v to find S.

$$gt = v. \qquad \text{(Formula 1, Falling Bodies.)}$$

$$t = \frac{v}{g}.$$

$$t^2 = \frac{v^2}{g^2}.$$

$$S = \tfrac{1}{2}gt^2. \qquad \text{(Formula 3, Falling Bodies.)}$$

Substituting the above value of t^2, we have,

$$S = \tfrac{1}{2}g \times \frac{v^2}{g^2} = \frac{v^2}{2g}.$$

Energy $= wS$ (the weight into the height). Substituting our new value for S, we have the following important formula:

$$\textbf{Kinetic Energy} = \frac{wv^2}{2g}.$$

158. Two Types of Energy.—There are two types of energy which may be designated as *energy of motion* and *energy of position*. With the first of these we are familiar. A falling weight or running stream, possesses energy of motion; it is able to overcome resistance by reason of its weight and velocity. On the other hand, before the weight began to fall, while, as yet, it had no

motion but was at rest, it had the power of doing work by reason of its elevated *position* with reference to the earth. When the water of the running stream was at rest in the lake among the hills it had a power of doing work, an energy, which was not possessed by the waters of the pond in the valley below. This energy or power results from its peculiar *position*. Energy of motion is called *kinetic* energy; energy of position is called *potential* energy.

159. Convertibility of Kinetic and Potential Energies.—We may at any moment convert kinetic energy into potential, or potential energy into kinetic. One is as real as the other, and when it exists at all, exists at the expense of a definite amount of the other. Imagine a ball thrown upward with a velocity of 64.32 feet. As it begins to rise it has a certain amount of kinetic energy. At the end of one second it has a velocity of only 32.16 ft. Consequently its kinetic energy has diminished. But it has risen 48.24 ft., and has already a considerable potential energy. All of this potential energy results from the kinetic energy which has disappeared. At the end of another second, the ball has no velocity; it has reached the turning-point and is at rest. Consequently, it has *no* kinetic energy. But the energy with which it began its flight has not been annihilated; it has been stored up in the ball at a height of 64.32 ft. as potential energy. If at this instant the ball be caught, all of the energy may be kept in store as potential energy. If now the ball be dropped, it begins to lose its potential and to gain kinetic energy. When it reaches the ground at the end of two seconds it has no potential energy, but *just as much* of the

kinetic type as was given to it when it began to rise. This illustrates in a simple way the important principle, *the transformation or convertibility of energy without any change in its quantity.*

160. Energy a Constant Quantity.—In the case of the ball thrown upward, at the start, at the finish, or at any intermediate point of either its ascent or descent, the sum of the two types of energy is the same. It may be all kinetic, all potential, or partly both. In any case, *the sum of the two continually varying energies is constant.* Just as a man may have a hundred gold dollars, now in his hand, now in his pocket, now part in his hand and the rest in his pocket; changing a dollar at a time from hand to pocket or *vice versa*, the amount of money in his possession remains constant, viz., one hundred dollars.

161. Pendulum Illustration.—The pendulum affords a good and simple illustration of kinetic and potential energy, their equivalence and convertibility. When the pendulum hangs at rest in a vertical position, as P*a*, it has no energy at all. Considered as a mass of matter, separated from the earth, it certainly *has* potential energy; but considered as a pendulum, it has no energy. If the pendulum be drawn aside to *b*, we raise it through the space *ah*; that is, we do work, or spend kinetic energy upon it. The energy thus

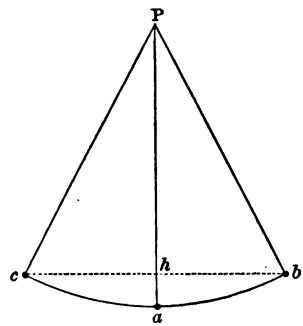


FIG. 36.

expended is now stored up as potential energy, ready to be reconverted into energy of the kinetic type, whenever we let it drop. As it falls the distance *ha*, in passing from *b* to *a*, this reconversion is gradually going on. When the pendulum reaches *a* its energy is all kinetic, and just equal to that spent in raising it from *a* to *b*. This kinetic energy now carries it on to *c*, lifting it again through the space *ah*. Its energy is again all potential just as it was at *b*. If we could free the pendulum from the resistances of the air and friction, the energy originally imparted to it would swing to and fro between the extremes of *all potential* and *all kinetic;* but at every instant, or at every point of the arc traversed, the total energy would be an unvarying quantity, always equal to the energy originally exerted in swinging it from *a* to *b*.

162. Indestructibility of Energy.—From the last paragraph it will be seen that, were it not for friction and the resistance of the air, the pendulum would vibrate forever; that the energy would be indestructible. Energy is withdrawn from the pendulum to overcome these impediments, but the energy thus withdrawn is not destroyed. What becomes of it will be seen when we come to study heat and other forms of energy, which result from the *motions* and *positions* of the molecules of matter. The truth is that *energy is as indestructible as matter.* For the present we must admit that a given amount of energy may disappear, and escape our search, but *it is only for the present.* We shall soon learn to recognize the fugitive even in disguise.

Note.—Physics may now be defined as the science of matter and energy.

EXERCISES.

1. How many horse-powers in an engine that will raise 8,250 lbs. 176 ft. in 4 minutes?

2. A ball weighing 192.96 pounds is rolled with a velocity of 100 feet a second. How much energy has it? *Ans.* 30000 foot-pounds.

3. A projectile weighing 50 Kg. is thrown obliquely upward with a velocity of 19.6 m. How much energy has it?

4. A ten-pound weight is thrown directly upward with a velocity of 225.12 ft. (*a.*) What will be its kinetic energy at the end of the third second of its ascent? (*b.*) At the end of the fourth second of its descent?

5. A body weighing 40 Kg. moves at the rate of 30 Km. per hour. Find its kinetic energy.

6. What is the horse-power of an engine that can raise 1,500 pounds 2,376 feet in 3 minutes?

7. A cubic foot of water weighs about $62\frac{1}{2}$ pounds. What is the horse-power of an engine that can raise 300 cubic feet of water every minute from a mine 132 ft. deep?

8. A body weighing 100 pounds moves with a velocity of 20 miles per hour. Find its kinetic energy.

9. A weight of 3 tons is lifted 50 feet. (*a.*) How much work was done by the agent? (*b.*) If the work was done in a half-minute, what was the necessary horse-power of the agent?

10. How long will it take a two horse-power engine to raise 5 tons 100 feet?

11. How far can a two horse-power engine raise 5 tons in 30 sec.?

12. What is the horse-power of an engine that can do 1,650,000 foot-pounds of work in a minute?

13. What is the horse-power of an engine that can raise 2,376 pounds 1,000 feet in 2 minutes?

14. If a perfect sphere rest on a perfect, horizontal plane in a vacuum, there will be no resistance to a force tending to move it. How much work is necessary to give to such a sphere, under such circumstances, a velocity of 20 feet a second, if the sphere weighs 201 pounds?

15. A railway car weighs 10 tons. From a state of rest it is moved 50 feet, when it is moving at the rate of 3 miles an hour. If the resistances from friction, etc., are 8 pounds per ton, how many foot-pounds of work have been expended upon the car? (First find the work done in overcoming friction, etc., through 50 ft. which is $10 \times 8 \times 50$ foot-pounds. To this add the work done in giving the car kinetic energy.)

Recapitulation.—In this section we have considered the meaning of Work and Energy; the Elements of Work-measure; the Unit of Work, as Foot-pound or Kilogram-meter; Horse-power; the relation between Velocity and Energy; a very convenient Formula for Energy; two Types of Energy, Kinetic and Potential; the mutual Convertibility of these two Types of Energy; the Sum of these two as a Constant Quantity; the Pendulum as an Illustration of this Convertibility and Constancy; the Indestructibility of Energy.

Review Questions and Exercises.

1. (*a.*) What is a molecule? (*b.*) An atom? (*c.*) Name the attractions pertaining to each.

2. (*a.*) Give an original illustration of a physical change. (*b.*) Of a chemical change.

3. (*a.*) What is the difference between general and characteristic properties of matter? (*b.*) Give an illustration of impenetrability, not mentioned in the book.

4. (*a.*) Upon what property do most of the characteristic properties of matter depend? (*b.*) Name five general and three characteristic properties of matter. (*c.*) Define inertia.

5. (*a.*) How does a solid differ from a liquid? (*b.*) From a gas? (*c.*) How does a gas differ from a vapor? (*d.*) What is a fluid?

6. (*a.*) Define dynamics. (*b.*) What is the difference between statics and kinetics? (*c.*) What is the gravity unit of force? (*d.*) The kinetic unit?

7. (*a.*) Give Newton's Laws of Motion. (*b.*) Explain the meaning of "parallelogram of forces." (*c.*) What is an equilibrant? (*d.*) Give the law of reflected motion.

8. (*a.*) What is the difference between gravity and gravitation? (*b.*) Give the law of gravitation. (*c.*) Of weight. (*d.*) What is meant by centre of gravity?

9. (*a.*) Describe the several kinds of equilibrium. (*b.*) Upon what does the stability of a body depend? (*c.*) Show how. (*d.*) What is the line of direction?

10. (*a.*) Why is it that a lead ball and a wooden ball will fall 100 feet in the same time? (*b.*) How did Galileo study the laws of falling bodies? (*c.*) Who was Galileo and when did he live? (*d.*) Define increment of velocity.

11. (*a.*) Give the laws of freely falling bodies. (*b.*) Express the same truths algebraically. (*c.*) What forces act upon a projectile? (*d.*) Define random.

12. (*a.*) What is a simple pendulum? (*b.*) A compound pendulum? (*c.*) What is the real length of a pendulum? (*d.*) How long must a pendulum be to vibrate once a minute? (*e.*) Once a second? (*f.*) What is the most important property of a pendulum?

13. Two forces of 6 and 8 pounds respectively act at right angles to each other. Find the direction and intensity of their equilibrant.

14. (*a.*) Define energy. (*b.*) Foot-pound. (*c.*) Horse-power. (*d.*) Give the rule for calculating horse-power.

15. (*a.*) What is a kilogram-meter? (*b.*) Give the formula for the calculation of kinetic energy from weight and velocity. (*c.*) Deduce the same.

16. (*a.*) State fully and clearly the difference between kinetic and potential energy. (*b.*) Illustrate the same by the pendulum.

17. (*a.*) What is the object of experiments in the study of physics? (*b.*) What is the metric unit of weight? (*c.*) How is it obtained?

18. Three inelastic balls weighing 5, 7 and 8 pounds, lie in the same straight line. The first strikes the second with a velocity of 60 feet per second; the first and second together strike the third. What will be the velocity of the third?

CHAPTER III.

SIMPLE MACHINES.

SECTION I.

PRINCIPLES OF MACHINERY.—THE LEVER.

163. What is a Machine?—*A machine is a contrivance by means of which the power can be applied to the resistance more advantageously.* Its general office is to effect a transformation in the intensities of energies, so that an energy of small intensity, acting through a considerable distance, may be made to reappear as an energy of considerable intensity, acting through a small distance, or *vice versa*.

164. A Machine cannot Create Energy.—No machine can create or increase energy. In fact, the use of a machine is accompanied by a waste of power which is needed to overcome the resistances of friction, the air, etc. A part of the energy exerted must therefore be used upon the machine itself, thus diminishing the amount that can be transmitted or utilized for doing the work in hand.

165.—A Common Error.—A clear understanding of this fact is very important. *There is a very common*

erroneous notion that, in some way or other, a machine performs work of itself—that it is *a source of power*. It were as reasonable to imagine that a bank is a source of real money. The bank can pay out no more than it receives; neither can a machine. A man may go to the bank with a ten-dollar gold piece, and get for it ten one-dollar gold pieces. In like manner, he may go to a machine with an ability of moving ten pounds one foot in a given time, and get for it the ability of moving one pound ten feet in the same time. He may exchange what he has for what he prefers; but, in the case of the bank and of the machine alike, the equivalent must be paid, and generally a commission for the transfer.

166. Of what Use are Machines?—Some of the many advantages resulting from the use of machines are:

(1.) It enables us to exchange intensity for a velocity otherwise unattainable, as in the case of the sewing machine or spinning wheel.

(2.) It enables us to exchange velocity for an intensity of power otherwise unattainable, as in the case of lifting a large stone with a crow-bar or pulleys.

(3.) It enables us to change the direction of our force, as in the case of hoisting a flag on a flag-staff. It would be inconvenient to climb the pole and then draw up the flag.

(4.) It enables us to employ other forces than our own, as the strength of animals, the forces of wind, water, steam, etc.

167. General Laws of Machines.—The work to be done by a machine is generally called the weight or load. The work of the power (*e. g.*, foot-pounds) is always

equal to the work of the load, the power expended in the machine itself being disregarded. The following laws are, therefore, applicable to machines of every kind. They are called the general or great laws of machines:

(1.) *What is gained in intensity of power is lost in time, velocity, or distance;* and what is gained in time, velocity, or distance is lost in intensity of power.

(2.) *The power multiplied by the distance through which it moves, equals the weight multiplied by the distance through which it moves.*

(3.) *The power multiplied by its velocity, equals the weight multiplied by its velocity.*

168. What is a Lever?—*A lever is an inflexible bar capable of being freely moved about a fixed point or line, called the fulcrum.*

In every lever, three points are to be considered, viz.: the fulcrum and the points of application for the power and the weight. Every lever is said to have two arms. The power-arm is the perpendicular distance from the fulcrum to the line in which the power acts; the weight-arm is the perpendicular distance from the fulcrum to the line in which the weight acts. If the arms are not in the same straight line, the lever is called a bent lever.

169. Classes of Levers.—There are three classes of levers, depending upon the relative positions of the power, weight, and fulcrum.

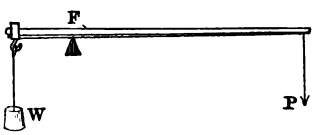


FIG. 37.

(1.) If the fulcrum is be-

tween the power and weight (P. F. W.), the lever is of the first class (Fig. 37); *e. g.*, crowbar, balance, steelyard, scissors, pincers.

(2.) If the weight is between the power and the fulcrum (P. W. F.), the lever is of the second class (Fig. 38); *e. g.*, cork-squeezer, nut-cracker, wheel-barrow.

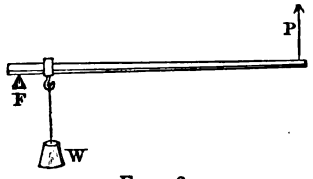


FIG. 38.

(3.) If the power is between the weight and the fulcrum (W. P. F.), the lever is of the third class (Fig. 39); *e. g.*, fire-tongs, sheep-shears, human fore-arm.

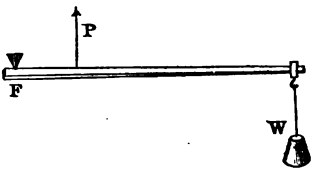


FIG. 39.

170. Static Laws of the Lever.—It will be clearly seen or may be geometrically shown that the ratio between the arms of the lever will be the same as the ratio between the velocities of the power and the weight, and the same as the ratio between the distances moved by the power and the weight. If the power-arm be twice as long as the weight-arm, the power will move twice as fast and twice as far as the weight does. The general laws of machines may therefore be adapted to the lever as follows:

$$P \times \text{power-arm} = W \times \text{weight-arm, or } P \times \overline{PF} = W \times \overline{WF}.$$

$$\therefore P : W :: \overline{WF} : \overline{PF}.$$

(1.) In the case of the lever, the power and weight are inversely proportional to the corresponding arms of the lever; or,

(2.) The power multiplied by the power-arm equals the weight multiplied by the weight-arm; or,

(3.) *A given power will support a weight as many times greater than itself, as the power-arm is times longer than the weight-arm.*

Note.—A static law expresses the relation between the power and weight when the machine is in equilibrium. In order that there be *motion*, one of the products mentioned in the law above must be greater than the other. The lever itself must be in equilibrium before the power and weight are applied. It is to be noticed that when we speak of the power multiplied by the power-arm, we refer to the abstract numbers representing the power and power-arm. We cannot multiply pounds by feet, but we can multiply the number of pounds by the number of feet.

171. The Moment of a Force.—The moment of a force acting about a given point, as the fulcrum of a lever, is *the product of the numbers representing respectively the magnitude of the force and the perpendicular distance between the given point and the line of the force.* In the case of the lever represented in Fig. 37, the weight-arm is 8 *mm.* and the power-arm is 30 *mm.* Suppose that the power is 4 grams, and let the weight be represented by x. Then the moment of the force acting on the power-arm will be represented by $(4 \times 30 =)$ 120, and the moment of the force acting on the weight-arm by $8x$.

172. Moments Applied to the Lever.—We sometimes have several forces acting upon one or both arms of a lever, in the same or in opposite directions.

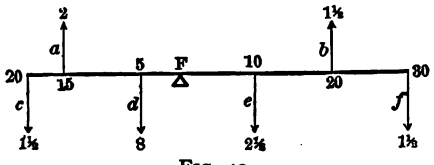


FIG. 40.

Under such circumstances, the lever will be in equilibrium, when the sum of the moments of the forces tending to turn the lever in one direction is equal to the sum of the moments of the forces tending to turn the lever in the other direction. Representing *the moments* of the several forces acting upon the lever represented in the figure by their respective letters and numerical values,

$$b+c+d=a+e+f \quad | \quad 30+30+40=30+25+45.$$
$$\text{or, } c+d-a=e+f-b \quad | \quad 30+40-30=25+45-30.$$

173. Bent Levers.—When the lever is not a straight bar, or *when, for any reason, the power and weight do not act parallel to each other,* it becomes necessary to distinguish between the *real* and *apparent* arms of the lever. This will be easily done, if you are familiar with the definition of the arms of a lever, given in § 168. In Fig. 41, we have represented a very simple kind of bent lever, which is sufficiently explained by the engraving. In Fig. 42, we have a representation of a curved rod lever, W′P′, at the ends of which two forces, not parallel, are acting. Our definition of the arms of the lever, already learned, removes every difficulty arising from the form of the lever, or the direction in which the forces act. The arms are not FP′ and FW′, but FP and FW.

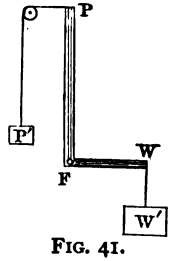


FIG. 41.

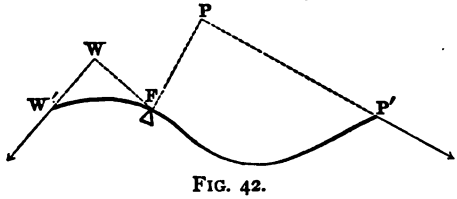


FIG. 42.

174. Load between Two Supports.—*If a beam rest on two supports, and carry a load between them, the beam may be considered a lever of the second class.* The part carried by either support may be found by considering it as the power, and the other support as the fulcrum. (Fig. 43.)

FIG. 43.

175. The Balance.—*The balance is essentially a lever of the first class, having equal arms.* Its use is to determine the relative weights of bodies. Its action depends upon the equality of moments explained in § 171 and § 172. The lever itself is called the beam. From the ends of the beam are suspended two pans, one to carry the weights used, the other to carry the article to be weighed. An index needle, or pointer, is often attached to the beam, and indicates equilibrium, by pointing to the zero of a graduated scale, carried by a fixed support.

(*a.*) That the balance may be accurate, the arms must be of the same length. To make these arms exactly equal is far from an easy task. That the balance may be delicate, it must turn upon its axis with

little friction, the axis of support must be a very little above the centre of gravity, the arms must be of considerable length, and the beam must be light. Balances are made so delicate that they may be turned by less than a thousandth of a grain. The supporting edge of the axis is made very sharp and hard, and rests upon two supports, generally made of agate or polished steel. A really good balance is an expensive piece of apparatus.

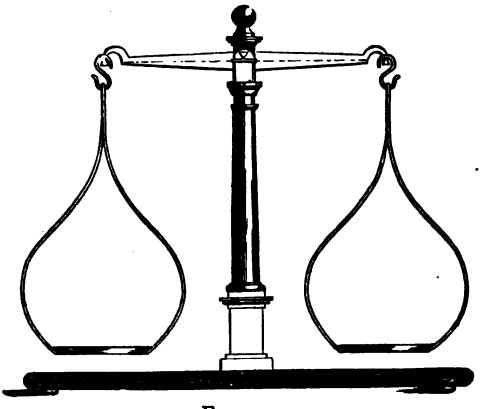


FIG. 44.

176. False Balances.—*False balances (levers of the first kind with unequal arms) are sometimes used by dishonest dealers.* When buying, they place the goods on the shorter arm; when selling, on the longer. The cheat may be exposed by changing the goods and weights to the opposite sides of the balance. The true weight may be found by weighing the article first on one side and then on the other, and taking the *geometrical* mean of the two false weights; that is, by finding the square-root of the product of the two false weights.

177. Double Weighing.—In another way the true weight of a body may be found with a false balance. The article to be weighed is placed in one pan, and a counterweight, as of shot or sand, placed in the other pan until equilibrium is produced. The article is then removed, and known weights placed in the pan until equilibrium is

again produced. The sum of these weights will be the true weight of the given article.

178. Compound Lever.—Sometimes it is not convenient to use a lever sufficiently long to make a given power support a given weight. A combination of levers called a compound lever may then be used. Hay-scales may be mentioned as a familiar illustration of the compound lever. In this case we have the following:

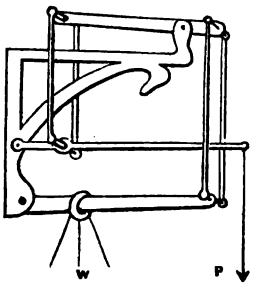


FIG. 45.

Statical Law.—*The continued product of the power and the lengths of the alternate arms, beginning with the power-arm, equals the continued product of the weight and the lengths of the alternate arms beginning with the weight-arm.*

EXERCISES.

No.	Power-Arm.	Weight-Arm.	Power.	Weight.	No.	Power-Arm.	Weight-Arm.	Power.	Weight.	Lever.	
										Leng.h.	Class.
1	4 ft.	2 ft.	50 lbs.	?	11	5 ft.	?	50 lbs.	25 lbs.	10 ft.	?
2	3 ft.	9 ft.	?	75 lbs.	12	?	?	15 oz.	45 oz.	12 in.	2
3	10 ft.	4 ft.	14 lbs.	?	13	?	50 cm.	1 Kg.	4 Kg.	?	2
4	60 in.	?	2 lbs.	30 lbs.	14	16⅔ cm.	?	12 oz.	2 oz.	?	3
5	?	18 cm.	27 Kg.	9 Kg.	15	3 ft.	5 ft.	10 lbs.	?	?	1
6	14 ft.	?	45 oz.	63 oz.	16	39.37 in.	50 cm.	?	20 Kg.	?	1
7	40 cm.	56 cm.	21 g.	?	17	?	16 ft.	14 lbs.	3½ lbs.	16 ft.	?
8	18 in.	21 in.	?	24 oz.	18	?	2 ft.	30 lbs.	?	10 ft.	1
9	26 cm.	?	11 Dg.	13 Dg.	19	?	2 ft.	30 lbs.	?	10 ft.	2
10	?	1 ft.	50 lbs.	2500 lbs.	20	2 ft.	?	30 lbs.	?	10 ft.	3

Note to the Pupil.—If any of these problems be obscure to you, remember that it will *pay* to draw an accurate figure or diagram of the machine representing the several powers and weights in position. See Fig. 40.

21. If a power of 50 pounds acting upon any kind of machine, move 15 feet, (*a*) how far can it move a weight of 250 pounds? (*b.*) How great a load can it move 75 feet?

22. If a power of 100 pounds acting upon a machine, moves with a velocity of 10 feet per second, (*a*) to how great a load can it give a velocity 125 feet per second? (*b.*) With what velocity can it move a load of 200 pounds?

23. A lever is 10 feet long; F in the middle; a power of 50 pounds is applied at one end; (*a*) how great a load at the other end can it support? (*b.*) How great a load can it lift?

Ans. to (*b.*): Anything less than 50 lbs.

24. The power-arm of a lever is 10 feet; the weight-arm is 5 feet. (*a.*) How long will the lever be if it is of the first class? (*b.*) If it is of the second? (*c.*) If it is of the third class?

25. A bar 12 feet long is to be used as a lever, keeping the weight 3 feet from the fulcrum. (*a.*) What class or classes of levers may it represent? (*b.*) What weight can a power of 10 pounds support in each case?

26. Length of lever = 10 feet. Four feet from the fulcrum and at the end of that arm is a weight of 40 pounds; two feet from the fulcrum on the same side, is a weight of 1,000 pounds. What force at the other end will counterbalance both weights?

27. At the opposite ends of a lever 20 feet long, two forces are acting whose sum = 1,200 pounds. The lengths of the lever arms are as 2 to 3; what are the two forces when the lever is in equilibrium?

28. Length of lever = 8 feet, F in the centre. A force of 10 pounds acts at one end, one foot from it another of 100 pounds. Three feet from the other end is a force of 100 pounds. Direction of all forces, downward. Where must a downward force of 80 pounds be applied to balance the lever?

29. Length of lever $ab = 6\frac{1}{4}$ feet; fulcrum at c; a downward force of 60 pounds acts at a; one of 75 pounds at a point d between a and c, $2\frac{3}{4}$ feet from the fulcrum; required the amount of force acting at b, the distance between b and c being $\frac{3}{4}$ feet.

30. On a lever ab, a downward force of 40 pounds acts at a, 10 feet from fulcrum c; on same side and $6\frac{1}{2}$ feet from c, an upward force, d, acts, amounting to 56 pounds; distance $bc = 3$ feet; a downward force of 96 pounds acts at b. (*a.*) Where must a fourth force of 28 pounds be applied to balance the lever, and (*b*) what direction must it have?

31. A beam 18 feet long is supported at both ends; a weight of 1 ton is suspended 3 feet from one end, and a weight of 14 cwt.,

8 feet from the other end. Give the pressure on each point of support.

32. Length of lever = 3 feet; where must the fulcrum be placed so that a weight of 200 lbs. at one end shall be balanced by 40 lbs. at the other end?

33. In one pan of a false balance, a roll of butter weighs 1 lb. 9 oz.; in the other, 2 lbs. 4 oz. Find the true weight.

34. A and B at opposite ends of a bar 6 ft. long carry a weight of 300 lbs. suspended between them. A's strength being twice as great as B's, where should the weight be hung?

35. A and B carry a quarter of beef weighing 550 pounds on a rod between them. A's strength is $1\frac{1}{2}$ that of B's; the rod is 8 feet long; where should the beef be suspended?

36. Length of lever = 16 feet; weight at one end, 100 pounds: what power applied at other end, $3\frac{1}{2}$ feet from the fulcrum, is required to *move* the weight?

37. A power of 50 lbs. acts upon the long arm of a lever of the first class; the arms of this lever are 5 and 40 inches respectively. The other end acts upon the long arm of a lever of the second class; the arms of this lever are 6 and 33 inches respectively. (*a.*) Figure the machine. (*b.*) Find the weight that may be thus supported. (*c.*) What power will support a weight of 4,400 kilograms?

Recapitulation.—In this section we have considered what a Machine is; its Inability to create Energy; a very common Error in this matter; the Uses of Machines; the Laws of Machines; what constitutes a Lever and its Arms; the Classes of Levers; Laws of the Lever; Moments of Force; the Nature of Bent Levers; a Beam resting on two Supports; the Balance, and False Balances; the Method of Double Weighing, and the Compound Lever.

SECTION II.

THE WHEEL AND AXLE AND WHEEL-WORK.

179. The Wheel and Axle.—The wheel and axle consists of *a wheel united to a cylinder in such a way that they may revolve together about a common axis.* It is a modified lever of the first class.

180. Advantages of the Wheel and Axle.—The ordinary range of action of a lever of the first class is very small. In order to raise the load higher than the vertical distance through which the weight end of the lever passes, it is necessary to support the load and re-adjust the fulcrum. This occasions an intermittent action and loss of time, difficulties which are obviated by using the wheel and axle.

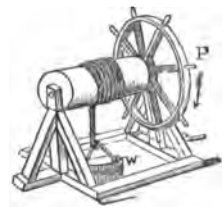


FIG. 46.

181. A Modified Lever.—Considered as a lever of the first class, the fulcrum is at the common axis, while the arms of the lever are the radii of the wheel and of the axle. If *a c*, the radius of the wheel, be used as the power-arm, velocity or time is exchanged for intensity of power. This is the usual arrangement. If *b c*, the radius of the axle, be used as the power-

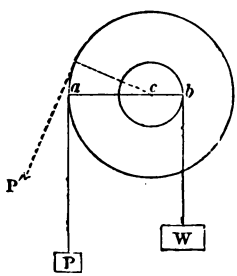


FIG. 47.

arm, there will be an exchange of intensity of power for velocity or time. In treating of the wheel and axle, unless otherwise specified, reference is made to the former or usual arrangement.

182. Formulas for Wheel and Axle.—The law and formula for the lever apply here:

$$P : W :: \overline{WF} : \overline{PF}, \quad \text{or,} \quad P : W :: r : R,$$

the radii of the wheel and of the axle respectively being represented by R and r. But it is a geometrical truth that in any two circles, the ratio of their radii is the same as the ratio of their diameters or circumferences. Hence these ratios may be substituted for the ratio between the radii of the wheel and axle; or,

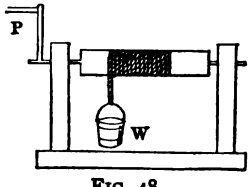


FIG. 48.

$$P : W :: r : R.$$
$$P : W :: d : D.$$
$$P : W :: c : C.$$

183. Law of Wheel and Axle.—*The power multiplied by the radius, diameter or circumference of the wheel equals the weight multiplied by the corresponding dimension of the axle.*

Note.—If the radius of the axle be made the power-arm, the formulas will be as follows:

$$P : W :: \overline{WF} : \overline{PF}, \quad \text{or,} \quad P : W :: D : d.$$

184. Various Forms of Wheel and Axle.—The wheel and axle appears in various forms. It is not necessary that an entire wheel be present, a single spoke or radius being sufficient for the application of the power,

as in the case of the windlass (Fig. 48) or capstan (Fig. 49). In all such cases, the radius being given, the diameter or circumference of the wheel may be easily computed. In one of the most common forms, the power is applied by means of a rope wound around the circumference of the wheel. When this rope is unwound by the action of the power, another rope is wound up by the axle, and the weight thus raised.

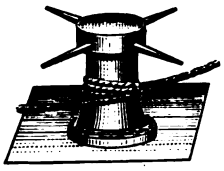


FIG. 49.

185. Wheel-work.—Another method of securing a great difference in the intensities of balancing forces, is to use a combination of wheels and axles of moderate size. Such a combination constitutes a train. The wheel that imparts the motion is called the *driver;* that which receives it, the *follower.* An axle with teeth upon it is called a *pinion.* The teeth or cogs of a pinion are called *leaves.*

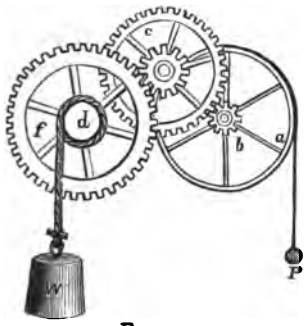


FIG. 50.

186. Law of Wheel-work.—A train of wheel-work is clearly analogous to a compound lever; the statical law, given in § 178, may be adapted to our present purposes as follows: *The continued product of the power and the radii of the wheels equals the continued product of the weight and the radii of the axles.*

187. Another Law of Wheel-work.—By examination of Fig. 50, it will be seen that while the axle

d revolves once, the wheel and pinion *c* will revolve as many times as the number of leaves borne by *c* is contained times in the number of teeth borne by *f*. In like manner, while the wheel *c* revolves once, the wheel and pinion *b* will revolve as many times as the number of leaves borne by *b* is contained times in the number of teeth borne by *c*. By combination of these results, we see that while *d* revolves once, *b* will have as many revolutions as the product of the number of leaves is contained times in the product of the number of teeth. From this it follows that the ratio between the continued product of the circumference (diameter or radius) of *d* into the number of leaves on the several pinions and the continued product of the corresponding dimension of *b* into the number of teeth on the several wheels will be the ratio between the distances or velocities of *W* and *P*, and therefore the ratio between the intensities of balancing weights or forces.

In short, the continued product of the power, the circumference of *a* and the number of teeth on *c* and *f* equals the continued product of the weight, the circumference of *d* and the number of leaves on the pinions *c* and *b*.

188. Example.—Suppose the circumferences of *a* and *d* to be 60 *mm.* and 15 *mm.* respectively; that *b* has 9 leaves; *c* has 36 teeth and 13 leaves; *f* has 40 teeth. Then will

$$P \times 60 \times 36 \times 40 = W \times 15 \times 13 \times 9.$$

189. Ways of Connecting Wheels.—Wheels may be connected in three ways:

(1.) By the friction of their circumferences.

(2.) By bands or belts.

(3.) By teeth or cogs.

The third of these methods has been already considered.

190. Uses of the First Two Ways.—The first method is used where no great resistance is to be overcome, but where evenness of motion and freedom from noise are chiefly desired. It is illustrated in some sewing-machines. The second method is used when the follower is to be at some distance from the driver. The friction of the belt upon the wheels must be greater than the resistance to be overcome. It is illustrated in most sewing-machines, and in the spinning-wheel.

191. Relation of Power to Weight Determined.—The follower will revolve as many times faster than the driver, as its circumference is contained times in that of the driver. The problem of finding the distances passed over in a given time by the power and weight, and thence the relative intensities of the power and the weight, thus becomes an easy one.

EXERCISES.—*The Wheel and Axle.*

Remark.—The circumference of a circle is 3.1416 times greater than its diameter.

No. of Problem.	Power.	Weight.	Dimensions.					
			R	*D*	*C*	*r*	*d*	*c*
1	25 lbs.	?	?	.....	20 ft.	.....	.....	4 ft.
2	?	750 Kg.	.....	.....	12.50 m.	.....	?	50 cm.
3	23 lbs.	290 lbs.	.....	15 ft.	.....	.....	?	?
4	9 Kg.	153 Kg.	.....	.....	?	.....	.....	17 cm.
5	1341 Kg.	?	.....	.....	628.32 cm.	.....	20 cm.	.....
6	195 lbs.	?	.....	.....	25 in.	.....	.....	15 in.
7	?	80 Kg.	1 m.	.....	.....	4 cm.	.....	.....
8	3 lbs.	48 lbs.	.....	16 in.	.....	?	?	.....
9	2 lbs.	40 lbs.	3 dm.	.....	.....	?	?	.....
10	49 lbs.	?	.....	16 in.	.....	.....	7 in.	.....
11	13 oz.	?	.....	.....	78.74 in.	.....	.....	10 cm.

12. The pilot-wheel of a boat is 3 feet in diameter; the axle, 6 inches. The resistance of the rudder is 180 pounds. What power applied to the wheel will move the rudder?

13. Four men are hoisting an anchor of 1 ton weight; the barrel of the capstan is 8 inches in diameter. The circle described by the handspikes is 6 feet 8 inches in diameter. How great a pressure must each of the men exert?

14. With a capstan, four men are raising a 1000 pound anchor. The barrel of the capstan is a foot in diameter; the handspikes used are 5 feet long; friction equals 10 *per cent* of the weight. How much force must each man exert to raise the anchor?

15. The circumference of a wheel is 8 ft.; that of its axle, 16 inches. The weight, including friction, is 85 pounds; how great a power will be required to raise it?

16. A power of 70 pounds, on a wheel whose diameter is 10 feet, balances 300 pounds on the axle. Give the diameter of the axle.

17. An axle 10 inches in diameter, fitted with a winch 18 inches long, is used to draw water from a well. (*a.*) How great a power will it require to raise a cubic foot of water which weighs 62½ lbs.? (*b.*) How much to raise 20 litres of water?

18. A capstan whose barrel has a diameter of 14 inches is worked by two handspikes, each 7 feet long. At the end of each handspike a man pushes with a force of 30 pounds; 2 feet from the end of each handspike, a man pushes with a force of 40 pounds; required the effect produced by the four men.

19. How long will it take a horse working at the end of a bar 7 feet long, the other end being in a capstan which has a barrel of 14 inches in diameter, to pull a house through 5 miles of streets, if the horse walk at the rate of 2½ miles an hour?

Recapitulation.—In this section we have considered the Definition of the Wheel and Axle; the Advantages of the wheel and axle over the lever; a Modified Lever of the first class; the Formulas and Laws of the wheel and axle; the Various Forms in which the wheel and axle appears; Trains of wheel-work and their parts; the Laws of such trains; the several Ways of Connecting Wheels and their several Advantages; how to find the Ratio of power to weight in the case of friction or belted wheels.

SECTION III.

THE PULLEY AND THE INCLINED PLANE.

192. What is a Pulley?—*A pulley consists of a wheel turning upon an axis and having a cord passing over its grooved circumference.* The frame supporting the axis of the wheel is called the block.

193. A Fixed Pulley.—The advantages arising from the use of a pulley depend upon the *uniform tension* of the cord. If a cord be passed over a pulley fixed to the ceiling, a weight being at one end and the hand applied at the other, the tension of the cord will be uniform, and the hand will have to exert a force equal to the weight of the load. If the weight be moved, the hand and weight will move equal distances. It is evident, then, that the *fixed pulley affords no increase of power, but only change of direction.*

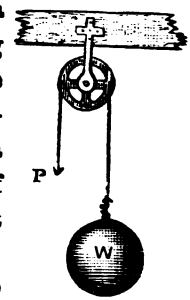


FIG. 51.

194. A Movable Pulley.—If one end of the cord be fastened to the ceiling, the load suspended from the pulley, and the other end of the cord drawn up by the hand, it will be evident, from the equal tension of the cord, that the fixed support carries half the load and the hand the other half. It is also evident that to raise the weight one foot the hand must pull up two feet of the cord; that is to

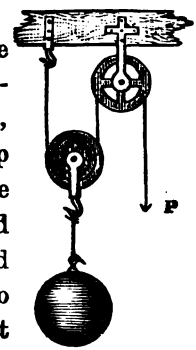


FIG. 52.

say, *each section* of the cord carrying the weight must be shortened one foot. Thus the hand, by lifting 50 pounds two feet, is able to raise 100 pounds one foot. It is to be noticed that we have here no creation or increase of energy, *working power*, but that we do secure an important transformation of velocity into intensity.

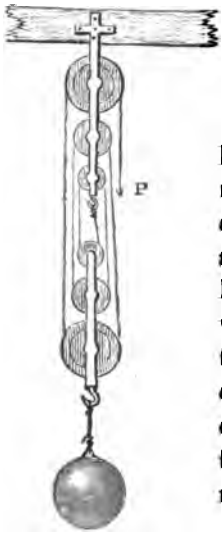


FIG. 53.

195. A Combination of Pulleys.—By the use of several fixed and movable pulleys in blocks, the number of parts of the cord supporting the movable block may be increased at pleasure. In all such cases, the tension of the cord will be uniform, and the part of the cord to which the power is applied, will carry only a *part of the load.* The value of this part of the load depends upon the number of sections into which the movable pulley divides the cord.

196. Law of the Pulley.—*With a pulley having a continuous cord, a given power will support a weight as many times greater than itself as there are parts of the cord supporting the movable block.*

FIG. 54.

197. Concerning the Number of Parts of the Cord.—By observing the several figures of pulleys in this section, it will be seen that when the fixed end of the cord is attached to the *fixed* block, the number of parts of the cord supporting the weight is twice the num-

ber of movable pulleys used; that when the fixed end of the cord is attached to the movable block the number of parts of the cord is one more than twice the number of movable pulleys used.

198. What is an Inclined Plane?—*The inclined plane is a smooth, hard, inflexible surface inclined so as to make an oblique angle with the direction of the force to be overcome.* In most cases it is a plane surface inclined to the horizon at an acute angle, and is used to aid in the performance of work against the force of gravity.

199. Resolution of the Force of Gravity.—When a weight is placed upon an inclined plane, the force of gravity tends to draw it vertically downward. This force may be resolved into two forces (§ 91), one acting perpendicularly to the plane, producing pressure completely resisted by the plane, the other component acting opposite to the direction of the power which it is to counterbalance. The first component shows how much pressure is exerted upon the plane; the other shows what force must be exerted to maintain equilibrium. The value of the second component will, plainly, vary with the direction of the power.

200. Three Cases.—In the use of an inclined plane, three cases may arise:

(1.) Where the power acts in a direction parallel to the length of the plane.

(2.) Where the power acts in a direction parallel to the base of the plane (generally horizontal).

(3.) Where the power acts in a direction parallel to neither the length nor the base of the plane.

201. The First Case.—In the accompanying figure, let

LM represent a plane inclined to the horizontal line *LN*. Let *A* represent a ball weighing 20 *Kg*. The problem is to find what force acting in the direction *LM* will hold it in equilibrium. The weight of the body *A* is a downward force of 20 *Kg*., which may be graphically represented (§ 81) by the vertical line *AC*, 20 *mm*. in length. Any other convenient unit of length might be used, but the scale of 1 *mm*. to the *Kg*. being adopted, it must be maintained throughout the problem. The force represented by *AC* is resolved into two components represented by *AD*, perpendicular to *LM*, and by *AB*, parallel to it. The former component measures the pressure to be resisted by the plane; the latter component measures the force with which the ball is drawn towards *L*. This second component is to be balanced by the equal and opposite force *AB'*, the equilibrant of *AB*. It may be proved geometrically that

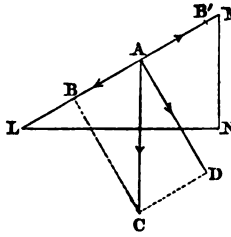


FIG. 55.

AB : AC :: MN : ML. (*Olney's Geometry*, Art. 341.)

Careful construction and measurement will give the same result. But *AB*, or rather its equal *AB'*, represents the power; *AC* represents the weight; *MN* represents the height; and *ML*, the length of the plane. Therefore,

$$P : W :: h : l, \quad \text{or,} \quad P = \text{the } \frac{h}{l} \text{ part of } W.$$

202. Law for the First Case.—In the figure above, ML is twice the length of MN, and AC is twice the length of AB or AB'. This indicates that a force of 10 *Kg*. acting in the direction LM would hold the ball in equilibrium. This result may be easily verified by experiment. We may therefore establish the following law: *When a given power acts parallel to the plane, it will support a weight as many times greater than itself as the length of the plane is times greater than its vertical height.*

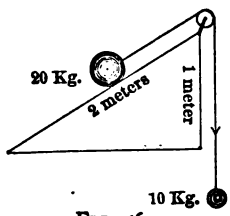


FIG. 56.

203. Law for the Second Case.—By resolving the force of gravity, or by experiment, the following law may be established: *When a given power acts parallel to the base, it will support a weight as many times greater than itself as the horizontal base of the plane is times greater than its vertical height.*

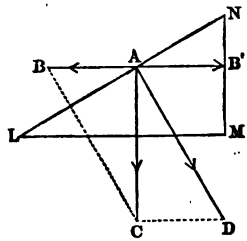


FIG. 57.

204. The Third Case.—For the third case, the power acting in a direction parallel to neither the length nor the base of the plane, no law can be given. The ratio of the power to the weight may be determined by resolving the force of gravity, as above explained, the construction and measurement being carefully done.

EXERCISES.

Remark.—The first problem may be read:

(*a.*) In a system of pulleys, the weight being supported by two sections of the cord, a power of 25 lbs. will support what weight?

(*b.*) In an inclined plane, the power acting in the direction of the length of the plane, the height of the plane being 3 ft., what must be the length that the same power may support the same weight?

No.	POWER.	WEIGHT.	PULLEY.	INCLINED PLANE.			
			Cords.	Height.	Length.	Base.	Case.
1	25 lbs.	?	2	3 ft.	?	.....	1
2	13 Kg.	78 Kg.	?	?	12 m.	.....	1
3	12 oz.	?	8	?	.....	2 ft.	2
4	250 g.	2 Kg.	?	1 dm.	?	.....	1
5	?	850 lbs.	7	?	.....	49 ft.	2
6	15 cwt.	3 T.	?	4 rds.	?	.....	1
7	20 g.	1 Hg.	?	?	.....	10 m.	2
8	500 Kg.	?	8	?	24 m.	.....	1
9	?	540 lbs.	9	39.37 in.	? m.	.....	1
10	75 lbs.	100 lbs.	.....	3 yds.	?	?	2

11. With a fixed pulley, what power will support a weight of 50 pounds?

12. With a movable pulley, what power will support a weight of 50 pounds?

13. What is the greatest effect of a system of 3 movable and 4 fixed pulleys, the power applied being 75 pounds?

14. With a system of 5 movable pulleys, one end of the rope being attached to the fixed block, what power will raise a ton?

15. If in the system mentioned in the problem above, the rope be attached to the movable block, what power will raise a ton?

16. With a pulley of 6 sheaves in each block, what is the least power that will support a weight of 1,800 pounds, allowing $\frac{1}{4}$ for friction? What will be the relative velocities of P and W?

17. Figure a set of pulleys by which a power of 50 pounds will support a weight of 250 pounds.

18. The height of an inclined plane is one-fifth its horizontal base. A globe weighing 250 *Kg.* is supported in place by a force acting at an angle of 45° with the base. The pressure of the globe upon the plane is *less* than 250 *Kg.* By construction and measurement, determine the intensity of the supporting force.

19. With the conditions as given in the last problem, except that the pressure of the globe upon the plane is *more* than 250 *Kg.*, determine the intensity of the supporting force.

20. The base of an inclined plane is 10 feet; the height is 3 feet. What force, acting parallel to the base, will balance a weight of 2 tons?

21. An incline has its base 10 feet; its height, 4 feet: how heavy a ball will 50 pounds power *roll up?*

22. How great a power will be required to support a ball weighing 40 pounds on an inclined plane whose length is 8 times its height?

23. A weight of 800 pounds rests upon an inclined plane 8 feet high, being held in equilibrium by a force of 25 pounds acting parallel to the base. Find the *length* of the plane.

24. A load of 2 tons is to be lifted along an incline. The power is 75 pounds; give the ratio of the incline which may be used.

25. A 1500 pound safe is to be raised 5 feet. The greatest power that can be applied is 250 pounds. Give the dimensions of the shortest inclined plane that can be used for that purpose.

Recapitulation.—In this section we have considered the Definition of a Pulley; the Action of a Fixed Pulley; of a Movable Pulley; Combina-

tions of Pulleys using a continuous Cord; the Law and Formula for such Pulleys; Definition of an Inclined Plane; how it resolves Gravity; the Three Cases that may arise; the Determination of the Law in the First Case; the Same in the Second Case; the Third Case; the Conformity of the Inclined Plane to the General Laws of Machines.

SECTION IV.

THE WEDGE, SCREW, COMPOUND MACHINES, AND FRICTION.

205. What is a Wedge?—*A wedge is a movable inclined plane in which the power generally acts parallel to the base.*

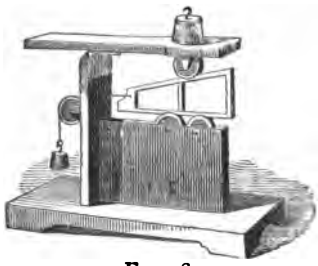


FIG. 58.

206. Its Use.—*This wedge is used for moving great weights short distances.* The law is the same as for the corresponding inclined plane. A common method of moving bodies is to place two similar wedges, with their sharp edges overlapping, under the load. Simultaneous blows of equal force are struck upon the heads of the wedges. In this case, the same force must be used upon each wedge as if only one were used, but the power being doubled

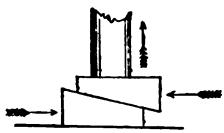


FIG. 59.

and the weight remaining the same, the distance moved is twice as great as when only one wedge is used.

207. A More Common Use.—*A more common kind of wedge is that of two inclined planes united at their bases.* Such wedges are used in splitting timber, stone, etc. The power is given in repeated blows instead of continued pressure. For a wedge thus used, no definite law of any practical value can be given, further than that, with a given thickness, the longer the wedge the greater the gain in intensity of power.

FIG. 60.

208. What is a Screw?—*A Screw is a cylinder, generally of wood or metal, with a spiral groove or ridge winding about its circumference.* The spiral ridge is called the *thread* of the screw. The thread works in a nut, within which there is a corresponding spiral groove to receive the thread.

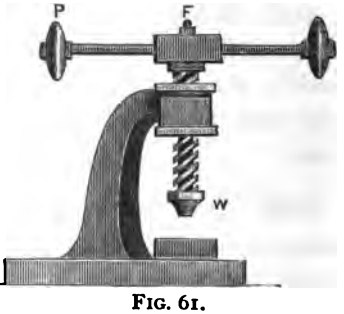


FIG. 61.

(*a.*) The power is used to turn the screw within a fixed nut, or to turn the nut about a fixed screw. In either case, a lever or wheel is generally used to aid the power. Every turn of the screw or nut either pushes forward the screw or draws back the nut by exactly the distance between two turns of the thread, this distance being measured in the direction of the axis of the screw. The weight or resistance at W is moved this distance, while the power at P moves over the circumference of a circle whose radius is PF. The difference between these distances is generally very great. Hence this machine affords great intensity of power with a corresponding loss of velocity.

209. Law of the Screw.—The second general law of machines (§ 167, [2]) may be adapted to our present purpose as follows: *With the screw, a given power will support a weight as many times greater than itself as the circumference described by the power is times greater than the distance between two adjoining turns of the thread.*

210. The Endless Screw.—*An endless screw is one whose thread acts on the teeth of a wheel.* The screw has a rotary but no lengthwise motion. As the handle is turned, the thread catches the teeth and turns the wheel. The wheel moves one tooth for every turn of the handle. Successive teeth are caught as others pass out of reach. A *continuous* motion is thus produced; hence the name "endless screw." The figure will aid in the application of the second general law of machines to determine the ratio between the weight and the power.

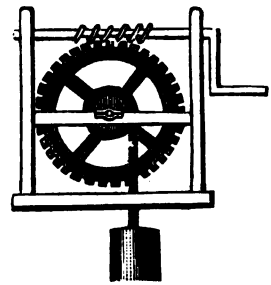


FIG. 62.

211. Compound Machines.—We have now considered each of the six traditional simple machines. One of these may be made to act upon another of the same kind, as in the case of the compound lever or wheel-work; or upon another of a different kind, as in the case of the endless screw. When any two or more of these machines are combined, the effective force may be found by computing the effect of each separately and then compounding them; or by finding the weight that the given power will

support, using the first machine alone, considering the result as a new power acting upon the second machine, and so on.

212. What is Friction?—The chief impediment to the motion of machinery arises from friction, which may be defined as *the resistance which a moving body meets with from the surface on which it moves.*

213. The Cause of Friction.—It is impossible, by any known means, to produce a perfectly smooth surface. Even a polished surface contains minute projections which fit into corresponding depressions on the corresponding surface. To produce motion of one surface on the other, these projections must be lifted out, bent down, or broken off.

214. Eight Facts Concerning Friction.—The following facts have been determined by experiment, and may be easily illustrated in the same way:

(1.) *Friction is greatest at the beginning of motion.* After surfaces have been in contact for some time, so that the projections of one have had opportunity to sink deeper into the depressions of the other, the resistance offered by friction is considerably increased. Every teamster and street-car driver is familiar with the fact.

(2.) *Friction increases with the roughness of the surfaces.*

(3.) *Friction is greater between soft bodies than hard ones.*

(4.) *Friction is nearly proportional to pressure.*

(*a.*) Place a brick upon a horizontal board. Around it fasten one end of a cord and pass the other end over a pulley so that it may hang vertically. Add just weights enough to keep the brick in

motion after it is started. The weights measure the friction. Place a second similar brick upon the first; the moving force must be doubled. Place another similar brick upon the other two; the original moving force must be tripled.

(5.) *Friction is not affected by extent of surface except within extreme limits.* In the case of the brick above mentioned, the moving force will be the same whether the brick lie on its broad face or on its side.

(6.) *Friction is greater between surfaces of the same material than between those of different kinds.*

(*a.*) Bodies of the same material have the same molecular structure (§ 10, *a*). Hence their little projections and cavities mutually fit each other as would the teeth of similar saws. A very little reflection will show that the element of *similarity* in molecular structure (just as with the saws) is very important in determining the amount of friction. For this reason, the axles of railway cars being made of steel, the "boxes" in which they revolve are made of brass or other different metal. Hence the advantages of a watch "full-jewelled," and hence the swiftness of the skillful skater.

(7.) *Rolling friction is less than sliding friction.*

(8.) *Friction is diminished by polishing or lubricating the surfaces.* An unequalled example of friction reduced to its *minimum* is in the case of the joints of animals.

EXERCISES.—*The Screw.*

No.	P.	W.	C.	*d.*	No.	P.	W.	C.	*d.*
1	15 lbs.	?	10 in.	½ in.	8	?	2500 Kg.	2.5 m.	1 cm.
2	5 Kg.	?	8 m.	1 cm.	9	4 oz.	6 lbs.	?	7 in.
3	1 lb.	?	75 in.	¼ in.	10	? lbs.	7874 lbs.	1 m.	1 in.
4	?	480 lbs.	15 in.	⅛ in.	11	3 Kg.	300 Kg.	20 cm.	?
5	20 lbs.	800 lbs.	?	⅛ in.	12	3 oz.	864 oz.	?	1 in.
6	25 lbs.	?	3 ft.	1 in.	13	100 lbs.	?	10 ft.	¾ in.
7	2 lbs.	192 lbs.	4 ft.	?	14	100 lbs.	?	10 ft.	½ in.

15. A book-binder has a press; the threads of its screw are $\frac{1}{3}$ in. apart; the nut is worked by a lever which describes a circumference of 8 ft. How great a pressure will a power of 15 lbs. applied at the end of the lever produce, the loss by friction being equivalent to 240 lbs.?

16. A screw has 11 threads for every inch in length. If the lever is 8 inches long, the power, 50 pounds, and friction is $\frac{1}{4}$ of the energy used, what resistance may be overcome by it?

17. A screw with threads $1\frac{1}{4}$ in. apart is driven by a lever $4\frac{1}{2}$ ft. long; what is the ratio of the power to the weight? (See App., Note *a*.)

18. How great a pressure will be exerted by a power of 15 lbs. applied to a screw whose head is one inch in circumference and whose threads are $\frac{1}{8}$ inch apart?

19. At the top of an inclined plane which rises 1 ft. in 20 is a wheel and axle. Radius of wheel $= 2\frac{1}{2}$ ft.; radius of axle $= 4\frac{1}{2}$ in. What load may be lifted by a boy who turns the wheel with a force of 25 lbs.?

20. The crank of an endless screw whose threads are an inch apart describes a circuit of 72 inches. The screw acts on the toothed edge of a wheel 60 inches in circumference. On the axle of this wheel, which is 10 inches in circumference, is wound a cord which acts upon a set of pulleys, 3 in each block. The effect of the pulleys is exerted upon the wheel of a wheel and axle. The diameters of the wheel and of the axle are 4 ft. and 6 inches respectively. What weight on the wheel and axle may be lifted by a force of 25 lbs. at the crank, allowing for a loss of $\frac{1}{4}$ by friction?

21. An endless screw which is turned by a wheel 10 ft. in circumference acts upon a wheel having 81 teeth; this wheel has an axle 18 inches in circumference; the power is 75 lbs. Find the value of the weight that may be suspended from the axle.

22. In moving a building the horse is attached to a lever 7 feet long, acting on a capstan barrel 11 inches in diameter; on the barrel winds a rope belonging to a system of 3 fixed and 3 movable pulleys. What force will be exerted by 500 pounds power, allowing $\frac{1}{4}$ for loss by friction?

Recapitulation.—In this section we have considered the Definition of the Wedge; the Uses and Examples of the Wedge; the Definition of the Screw; the Law and Formula for the Screw; the Endless Screw; the Definition of Friction; the Cause of Friction; Eight Facts concerning Friction.

Review Questions and Exercises.

1. (*a.*) What is a machine? (*b.*) What is a machine good for? (*c.*) State the general laws of machines and (*d*) illustrate by the pulley.

2. (*a.*) What are the *arms* of a lever? (*b.*) What is meant by the moment of a force? (*c.*) Illustrate the equality of moments in machines by the wheel and axle.

3. (*a.*) What are the respective advantages to be gained by the several classes of levers? (*b.*) Explain the advantage gained by a claw hammer in drawing a nail. (*c.*) What is meant by double weighing?

4. With a lever of given length, in which class will a given power yield the greatest intensity of effect?

5. (*a.*) To what kind of a lever is ordinary clock-work analogous? (*b.*) Show why.

6. (*a.*) Does it require *more work* to lift a barrel of flour into a wagon four feet high than to place it there by rolling it up a plank 12 feet long? (*b.*) Show why.

7. (*a.*) Give the static law for the inclined plane when the power acts parallel to the plane. (*b.*) When it acts parallel to the horizon. (*c.*) Figure a system of pulleys by means of which a weight of 5 pounds will support a weight of 25 pounds.

8. (*a.*) Figure a system of 4 movable pulleys by means of which a weight of 3 lbs. will support a weight of 27 lbs. (*b.*) Deduce the formula for the screw from one of the general laws of machines.

9. (*a.*) In raising a boy from a deep well by means of a common rope and pulley, what disadvantages arise from friction? (*b.*) What immense advantage?

10. (*a.*) Explain the cause of friction. (*b.*) Why is friction between iron and iron greater than that between iron and brass?

11. (*a.*) How may the centre of gravity of a ring be determined? (*b.*) What is the value in inches of the metric unit of length?

12. A body moving with a force of 20 foot-pounds, strikes the end of the arm of a lever of the first class, four feet from the fulcrum. (*a.*) How many foot-pounds will be exerted by the other end of the lever, 6 feet from the fulcrum? (*b.*) How far would it raise a weight of 4 pounds?

13. Deduce the static law for the inclined plane, first case, by resolution of the force of gravity.

14. (*a.*) What force is necessary to overturn a body? (*b.*) What difference between the forces producing uniform and accelerated velocities? (*c.*) Show that the screw is a modified inclined plane.

CHAPTER IV.

LIQUIDS.

SECTION I.

HYDROSTATICS.

215. Incompressibility of Liquids.—Liquids are nearly incompressible. A pressure of 15 pounds to the square inch compresses distilled water only $\frac{1}{20000}$ part of its volume; it compresses mercury only one-tenth as much. This virtual incompressibility of liquids is of the highest practical importance.

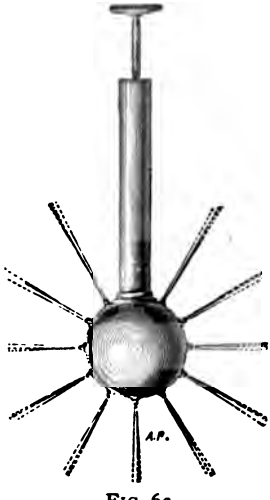


FIG. 63.

216. Transmission of Pressure.—*Fluids can transmit pressure in every direction, upward, downward, and sidewise at the same time.*

(*a.*) This property of liquids may be illustrated by the apparatus represented in Fig. 63. The globe and cylinder being filled with water and the several openings in the globe closed by corks, a piston is pushed

down the cylinder. The pressure thus received and transmitted by the confined water expels the cork and throws a jet of water from each aperture. (See Appendix D.)

(*b.*) The explanation of this property of fluids may be seen by reference to Fig. 64, representing five molecules of any fluid. If a downward pressure be applied to 1, it will force 2 toward the right and 3 toward the left, thus forming lateral pressure. When thus moved, 3 will force 4 upward and 5 downward. Owing to the freedom with which the molecules move on each other, there is no loss by friction, and the downward pressure of 5, the upward pressure of 4, and the lateral pressure of 2, will each equal the pressure exerted by 1. It makes no difference with the fact, whether the pressure exerted by 1 was the result of its own weight only, this weight together with the weight of overlying molecules, or both of these with still additional forces.

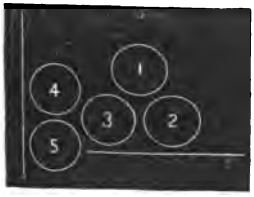


FIG. 64.

217. Pascal's Law.—*Pressure exerted anywhere upon a mass of liquid is transmitted undiminished in all directions, and acts with the same force upon all equal surfaces and in a direction at right angles to those surfaces.*

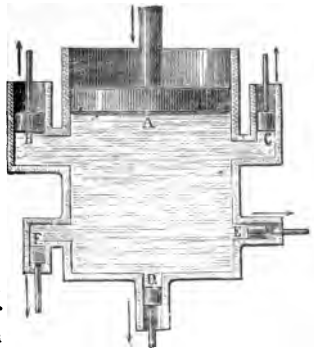


FIG. 65.

218. An Argument from Pascal's Law.—Fill with water a vessel of any shape, having in its sides apertures whose areas are respectively as 1, 2 and 3, each aperture being closed with a piston. Suppose the pistons to move without friction and the water to have no weight; then there will be no motion. Suppose that the piston whose area is represented by 1 rests upon 1000 molecules of the water; then will the piston at 2 rest upon 2000, and that at 3 upon 3000 molecules of water. If now a pressure of one pound be applied to the piston at 1, this

pressure is distributed among the 1000 molecules upon which it presses. Owing to this freedom of motion, these molecules will transmit this pressure to those adjacent, and these to those beyond, until every molecule of water in the vessel exerts a pressure equal to that exerted upon any one of the molecules upon which the pressure was originally exerted, *i. e.*, every thousand molecules in the vessel will exert a force of one pound. Then will the 2000 molecules at 2 exert a force of two pounds and the 3000 molecules at 3 will exert a force of three pounds.

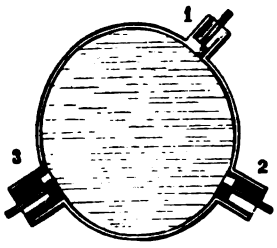


FIG. 66.

219. An Important Principle.—The foregoing argument may be summed up as follows: *When fluids are subjected to pressure, the pressure sustained by any part of the restraining surface is proportional to its area.*

220. Experimental Proof.—The above principle, which we deduced from Pascal's law, may be verified by experiment. Provide two communicating tubes of unequal sectional area. When water is poured into these, it will stand at the same height in both tubes. If by means of a piston the water in the smaller tube be subjected to pressure, the pressure will force the water back into the larger tube and raise its level there. To prevent this result, a piston must be fitted to the larger tube and held there with a force as many times greater than the force acting upon the other

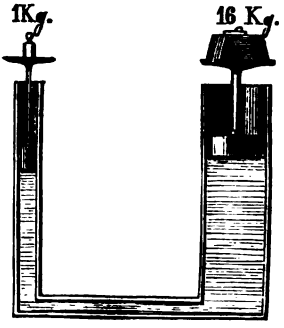


FIG. 67.

piston as the area of the larger piston is times greater than the area of the smaller one. If, for example, the smaller piston have an area of 1 sq. cm. and the larger piston an area of 16 sq. cm., a weight of 1 Kg. may be made to support a weight of 16 Kg.

FIG. 68.

221. Pascal's Experiment.—Pascal firmly fixed a very narrow tube about 30 ft. high into the head of a stout cask. He then filled the cask and tube with water. The weight of the small amount of water in the tube, producing a pressure as many times greater than itself as the inner surface of the cask was times greater than the sectional area of the tube, actually burst the cask.

222. The Hydrostatic Bellows.—*The hydrostatic bellows consists of two boards fastened together by a broad band of stout leather, and a small vertical tube communicating with the interior.* If the tube have a sectional area of 1 sq. cm., the downward pressure at *b*, its base, will be one gram for every centimeter of depth of water in the tube. If the upper board, *B*, have a surface of 1000 sq. cm. exposed to the water in the bellows, it will be pressed upward with a

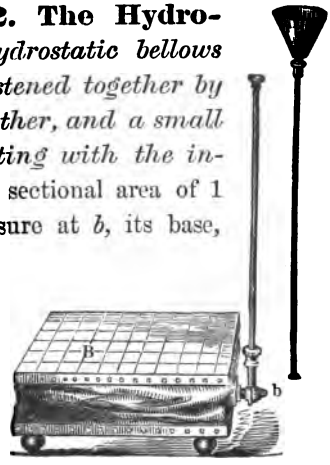


FIG. 69.

force of 1000 g. for every gram of downward pressure at *b*. If the tube be 2 meters high the downward pressure at *E* will be 200 g., and the upward pressure exerted on *B* will be 200 g. $\times$ 1000 = 200,000 g. or 200 Kg.

FIG. 70.

223. The Hydrostatic Press.—The hydrostatic press, often called the Hydraulic, or Bramah's press, acts upon the same principle. It is represented in perspective by Fig. 70 and in section by Fig 71. Instead of the downward pressure produced by the weight of the water in the tube, pressure is produced by the force-pump. Instead of the two boards and the leather band, a large,

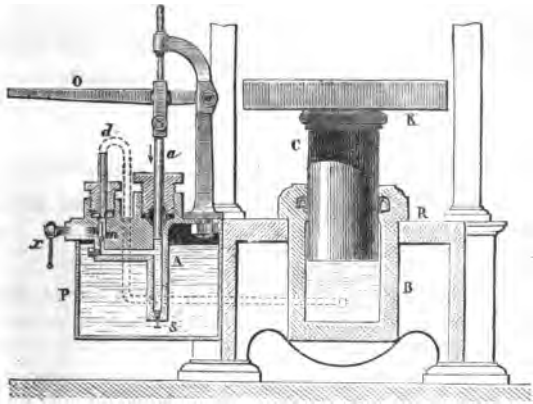


FIG. 71.

strong reservoir and a piston, working water-tight, are used. The substance to be pressed is placed between K, the head of the piston, and an immovable plate MN. The reservoir and the cylinder of the pump are connected by the tube *d*. By the action of the pump, the water in the cylinder *A* is subjected to pressure, and this pressure is transmitted undiminished to the water in *B*. According to the law given in § 219, the power exerted upon the lower surfaces of the two pistons is proportional to their respective areas. But the force exerted by the water upon the under surface of the piston in the pump is the same as the force exerted upon the water by that piston, (equality of action and reaction). The piston *a* is generally worked by a lever of the second class, resulting in a still further gain of intensity of power. If the power arm of the lever be ten times as long as the weight-arm, a power of 50 Kg. at the end of the lever will exert a pressure of 500 Kg. upon the water in *A*. If the piston in *A* have a sectional area of 1 sq. cm. and the piston in *B* have an area of 500

sq. cm., then the pressure of 500 Kg. exerted by the small piston will produce a pressure of 500 Kg. $\times$ 500 = 250,000 Kg. upon the lower surface of the large piston. Hence the following rule:

Multiply the pressure exerted by the piston of the pump by the ratio between the sectional areas of the two pistons.

(*a*.) The accompanying figure shows a device due to Ritchie of Boston. It consists of a base B; a sliding platform P guided by two vertical pillars; a bellows-formed rubber bag connecting the base and platform; and a bag or flask F, fitted with a cap and cork. The flask is connected with the base by flexible tubing. A weight W is placed upon the platform. Fill the globe with water, and elevate it; the pressure of the column will force the water into the bellows, raising the weight; lower the globe, and the weight will force the water back into it.

FIG. 72.

224. Liquid Pressure Due to Gravity.—The pressure exerted by liquids, on account of their weight, may be downward, upward, or lateral. Pressure in any other direction may be resolved into two of these. We shall now briefly consider these three kinds of liquid pressure.

225. Downward Pressure.—*The pressure on the bottom of a vessel containing a liquid, is independent of the quantity of the liquid or the shape of the vessel, but depends upon the depth and density of the fluid and the area of the bottom.*

(*a.*) Pascal contrived a neat experiment to verify this principle. The apparatus consists of a wooden support carrying a ring into which may be screwed any one of three vessels, one cylindrical, one widening upward and one narrowing upward, straight or bent. On the lower side of the ring is a plate *a*, supported by a thread from

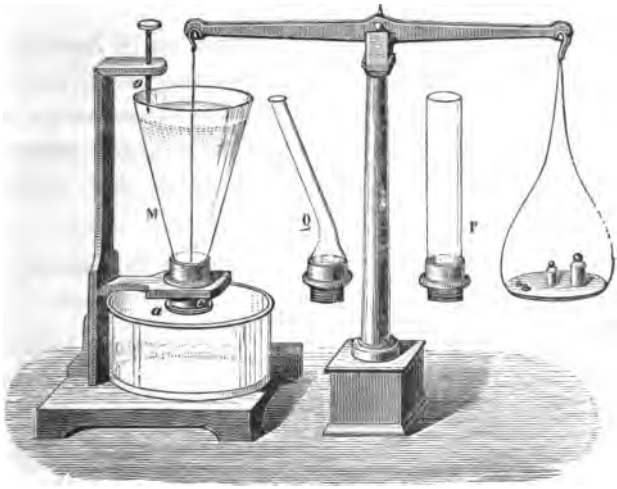


FIG 73.

one end of an ordinary balance. The other end of the balance carries a scale-pan. Weights in the scale-pan hold the plate *a* against the ring with a certain force. Water is carefully poured into M until the pressure forces off the plate and allows a little of the water to escape. A rod *o* marks the level of the liquid when this takes place. Repeating the experiment with the same weights in the scale-pan, and either P or Q in the place of M, the plate will be detached when the water has reached the same height although the quantity of water is much less.

226. Rule for Downward Pressure.—When the cylindrical vessel, mentioned in the last paragraph, is filled, it is evident that the downward pressure is equal to the weight of the contained liquid. It is further evident

that the weight of the counterpoise in the scale-pan, the weight of the liquid contained in P, and the downward pressure exerted on the plate by the liquid contained in M, P, or Q are equal. We therefore deduce the following rule:

To find the downward pressure on a horizontal surface, find the weight of an imaginary column of the given liquid, whose base is the same as the given surface, and whose altitude is the same as the depth of the given surface below the surface of the liquid.

Note.—A cubic foot of water weighs about 1000 ounces, 62½ pounds (more exactly 62.42 lbs.).

227. Upward Pressure.—Some persons have difficulty in understanding that liquids have *upward* pressure. This upward pressure may be illustrated as follows: Take a glass tube open at both ends, having at its lower end a glass disc supported from its centre by a thread. If this apparatus be placed in water, the tube being vertical, the upward pressure of the water will hold the disc in its place. If the disc does not accurately fit the end of the tube, water will be forced into the tube, and gradually fill it from below. If the disc does fit accurately, as is desirable, pour water carefully into the tube. In either case, the disc will be

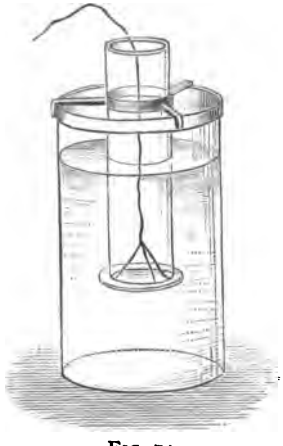


FIG. 74.

held in place against the force of gravity until the level of the water within the tube is very nearly the same as that in the outer vessel. The disc will not fall until the weight of the water in the tube *plus* the weight of the disc equals the upward pressure.

Note.—A lamp-chimney answers the purpose of this experiment. On the glass disc pour a little fine emery powder, and on this rub the end of the lamp-chimney until they fit accurately. The string may be fastened to the disc with wax.

228. Rule for Upward Pressure.—*To find the upward pressure on any horizontal surface, find the weight of an imaginary column of the given liquid whose base is the same as the given surface, and whose altitude is the same as the depth of the given surface below the surface of the liquid.*

229. The Hydrostatic Paradox.—It may seem strange at first thought that vessels whose bottoms are subjected to equal pressure, like those represented in Fig. 75, do not exert equal pressures upon the stand supporting them; in other words, that they do not weigh the same. The difficulty will be removed by remembering that *the pressure on the bottom of the vessel is only one of the elements which combine to produce the pressure upon the stand.* By reference to the figure, which represents three vessels of unequal capacity but having equal pressures upon the bot-

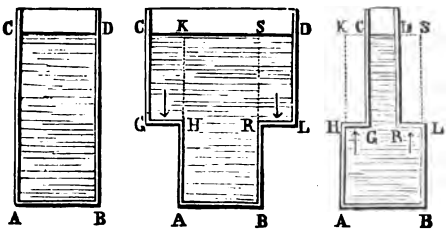


FIG 75.

tom, it will be seen that the weight may be the resultant of several forces, compounded according to the first and second cases specified in § 80.

230. Lateral Pressure.—We have already seen that downward and upward pressure are proportional to the depth of the liquid. Owing to the principle of equal transmission of pressure in all directions, the same holds true for lateral pressure, the effects of which are sometimes disastrously shown by the giving way of flood-gates, dams, and reservoirs.

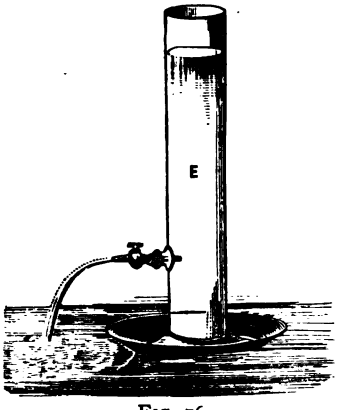


FIG. 76.

(*a.*) These effects of lateral pressure may be safely illustrated by a tall vessel provided with a stop-cock near its base, and arranged to float upon the water. When this vessel is filled with water, the lateral pressure at any two points at the same depth and opposite each other will be equal. Being equal and opposite they will neutralize each other and produce no motion. If now the stop-cock be opened, the pressure at that point tending to drive the apparatus in a certain direction, say toward the left, is removed; the pressure at the opposite point tending to drive the vessel toward the right, being no longer opposed by its equal, will now produce motion and the vessel will float in a direction opposite to that of the spouting water. Instead of being floated upon water, the vessel may be supported by a long thread. The same principle is illustrated in Barker's Mill. (Fig. 91.)

231. Rule for Lateral Pressure.—*To find the pressure upon any vertical surface, find the weight of an imaginary column of the liquid whose base is equal to the given surface and whose altitude is the same as the depth of the centre of the given surface below the surface of the liquid.*

EXERCISES.

1. What will be the pressure on a dam in 20 feet of water, the dam being 30 feet long?

2. What will be the pressure on a dam in 6 *m.* of water, the dam being 10 *m.* long?

3. Find the pressure on one side of a cistern 5 feet square and 12 feet high, filled with water.

4. Find the pressure on one side of a cistern 2 *m.* square and 4 *m.* high, filled with water.

5. A cylindrical vessel having a base of a sq. yd., is filled with water to the depth of two yards. What pressure is exerted upon the base?

6. A cylindrical vessel having a base of a *sq. m.* is filled with water to the depth of two meters. What pressure is exerted upon the base?

7. What will be the upward pressure upon a horizontal plate a foot square at a depth of 25 ft. of water?

8. What will be the upward pressure upon a horizontal plate 30 *cm.* square at the depth of 8 *m.* of water?

9. A square board with a surface of 9 square feet is pressed against the bottom of the vertical wall of a cistern in which the water is $8\frac{1}{2}$ feet deep. What pressure does the water exert upon the board?

10. A cubical vessel with a capacity of 1728 cubic inches is two-thirds full of sulphuric acid, which is 1.8 times as heavy as water. Find the pressure on one side.

11. A conical vessel has a base with an area of 237 *sq. cm.* Its altitude is 38 *cm.* It is filled with water to the height of 35 *cm.* Find the pressure on the bottom. *Ans.* 8295 *g.*

12. In the above problem, substitute inches for centimeters, and then find the pressure on the bottom.

13. What would be the total liquid pressure on a prismatic vessel containing a cubic yard of water, the bottom of the vessel being 2 by 3 feet?

14. The lever of a hydrostatic press is 6 feet long, the piston-rod being 1 foot from the fulcrum. The area of the tube is one-half square inch; that of the cylinder is 100 square inches. Find the weight that may be raised by a power of 75 lbs.

15. What is the pressure on the bottom of a pyramidal vessel filled with water, the base being 2 by 3 feet, and the height, 5 feet?

16. What is the pressure on the bottom of a conical vessel 4 feet high filled with water, the base being 20 inches in diameter?

Recapitulation.—In this section we have considered Incompressibility; the Transmission of Pressure with Explanation and Illustration; Pascal's Law with Argument and Conclusion therefrom; one of Pascal's Experiments; the Hydrostatic Bellows; the Hydrostatic Press; Downward Pressure with experimental illustrations; Rule for computing downward pressure; Upward Pressure with experimental illustrations; Rule for computing upward pressure; Lateral Pressure with experimental illustrations; Rule for computing lateral pressure.

SECTION II.

EQUILIBRIUM.—CAPILLARITY.—BUOYANCY.

232. Conditions of Liquid Rest.—The force of gravity tends to draw all liquid particles as near the earth's centre as possible. The following are necessary conditions, that a liquid may be at rest:

(1.) *The free surface of the liquid must be everywhere perpendicular to the force of gravity, i. e.*, horizontal. In the case of the ocean, this condition is modified by the so-called centrifugal force, which gives rise to the spheroidal shape of the earth.

(2.) *Every molecule must be subjected to equal and contrary pressures in every direction.*

233. Equilibrium of Liquids.—A liquid of small surface area is said to be level when all the points of

its surface are in the same horizontal plane. The central idea is expressed in the familiar saying, *water seeks its level.* This is true whether the liquid be placed in a single vessel or in several vessels that communicate with each other.

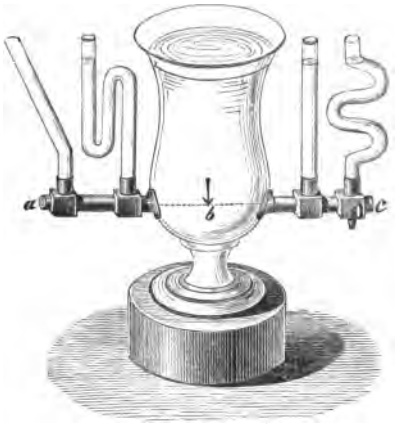


FIG. 77.

234. Communicating Vessels.— When any liquid is placed in one or more of several vessels communicating with each other, *it will not come to rest until it stands at the same height in all of the vessels,* so that all of the free surfaces lie in the same horizontal plane. This principle is prettily illustrated by the apparatus represented in Fig. 77. It consists of such communicating vessels containing a liquid.

(*a.*) This important principle that "water seeks its level" finds a gigantic illustration in the system of water-pipes by which water is distributed in cities and large towns. Brought or pumped into an elevated reservoir near the city, the water flows, in obedience to the force of gravity, through all the turns and windings of all the pipes connected with the reservoir, and is thus brought into thousands of buildings. Into any of the rooms of any of these houses the water may thus be led, *provided only* that the ends of the pipes be below the level of the water in the reservoir.

(*b.*) Among the many other results of this tendency of water to seek its level may be mentioned the action of springs and Artesian wells, the use of locks on canals, the spirit-level, the flow of streams, etc.

235. Capillary Attraction. — The statements made concerning the equilibrium of liquids are subject to one important modification. When the vertical sides of the containing vessel are very near each other, as in the case of small tubes, the force of adhesion manifests itself in a way known as *capillary attraction.*

236. Capillary Phenomena.—If a clean glass rod be placed vertically in water, the water will rise above its level at the sides of the glass. If the rod be now plunged into mercury, this liquid will be depressed instead of raised. If the experiments be repeated, it may be noticed that the water *wets the glass* while the mercury does not. If the glass be smeared with grease and placed in water, the surface of the water will be depressed; if a clean lead or zinc plate be placed in the mercury the surface of the

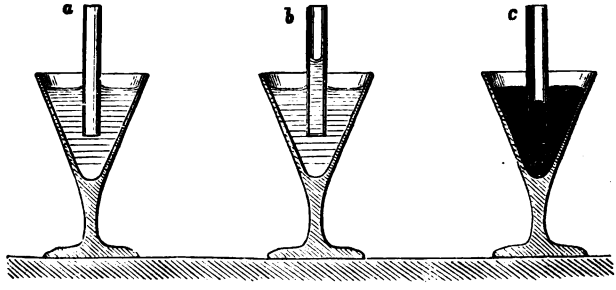


FIG. 78.

mercury will be raised. In this case the greased glass will come out dry, no water adhering to it, while mercury will adhere to the lead or zinc. This is found to be invariably true: *all liquids that will wet the sides of solids placed in them will be lifted, while those that do not will be pushed down.* In the figure, *a* represents

a glass rod in water; *b*, a glass tube in water; and *c*, a glass tube in mercury.

(*a*.) This form of adhesion is known as capillary attraction because its phenomena are best shown in tubes as fine as a hair (Latin *capillus*). If fine glass tubes be placed in water, the liquid will rise, wet the tube, and have a concave surface. If they be placed in mercury, the liquid will be depressed, will not wet the tube, and will have a convex surface. *The finer the tube, the greater the capillary ascent or depression.*

237. Displacement of a Fluid by an Immersed Solid.—*A solid immersed in a fluid will displace exactly its own bulk of the fluid.* This may be proved, if desirable, by plunging a heavy body of known volume, as a cubic centimeter of iron, into water contained in a glass vessel graduated to cubic centimeters. The water will rise just as if another cubic centimeter of water had been added. Thus, the volume of any irregularly shaped body may be found.

238. Archimedes' Principle.—*The loss of weight of a body immersed in a fluid equals the weight of the fluid which it displaces.*

(*a*.) It is a familiar fact that a person may easily raise to the surface of the water a stone which he cannot lift any further. When an arm or leg is lifted out of the water of a bath-tub, there is a sudden and very perceptible increase of weight at the surface. Let us try to find a reason for these familiar truths Imagine a cube, six centimeters on a side, immersed in water so that four of its surfaces are vertical and its upper horizontal surface twelve centimeters below the surface of the water. The lateral pressures which the water exerts upon any two opposite vertical surfaces are clearly equal and opposite. They will have no tendency to move the body. But the vertical pressures upon the two horizontal surfaces are not equal. The lower face will be pressed upward with a force represented by the weight of (6 × 6 × 18 =)

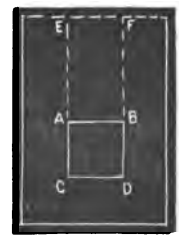


FIG. 79.

648 *cu. cm.* of water (see § 228) while the upper face will be pressed downward with a force represented by the weight of ($6 \times 6 \times 12 =$) 432 *cu. cm.* of water. The resultant of all these forces, therefore, will be an upward pressure represented by the weight of ($648 - 432 =$) 216 *cu. cm.* of water. But 216 *cu. cm.* is the volume of the cube. *This upward pressure or buoyant effort is exerted against the force of gravity,* and diminishes the weight of the cube.

239. An Experimental Demonstration.— This principle of Archimedes may be experimentally verified as follows: From one end of a scale-beam suspend a

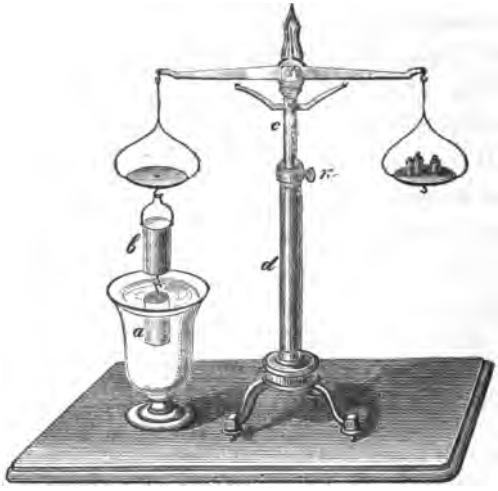


FIG 80.

cylindrical bucket of metal, *b*, and below that a solid cylinder, *a*, which accurately fits into the bucket. Counterpoise with weights in the opposite scale-pan. Immerse *a* in water and the counterpoise will descend, showing that *a* has lost some of its weight. Carefully fill *b* with water. It will hold exactly the quantity displaced by *a*. Equilibrium will be restored.

(*a.*) Insert a short spout in the side of a vessel (as a tin fruit-can) about an inch below the top. Fill the vessel with water and let all above the level of the spout escape. This is to replace the vessel of water in which *a* (Fig. 80) is immersed. Instead of the bucket, *b*, use a cup placed on the scale pan. Instead of *a*, use any convenient solid heavier than water, as the fragment of a stone. Counterpoise the cup and stone in the air. Immerse the stone in the water and catch, in any convenient vessel, every drop of water that overflows. This will be the fluid that the solid displaces. The equilibrium is destroyed, but may be restored by pouring the water just caught into the cup on the scale-pan.

240. Floating Bodies.—When solids of different densities are thrown into a given liquid, those having densities greater than that of the liquid will sink, because the force of gravity overcomes the buoyancy of the liquid; those having densities equal to that of the liquid will remain at rest in any position in the liquid, because the opposing forces, gravity and buoyancy, are equal; those having densities less than that of the liquid will float, because the force of gravity will draw them down into the liquid until they displace enough of the liquid to render the buoyant effect equal to the weight. Hence, *a floating body displaces its own weight of the fluid.* This may be shown experimentally by filling a vase with water. When a floating body is placed on the surface, the water displaced will overflow and may be caught. The water thus caught will weigh the same as the floating body.

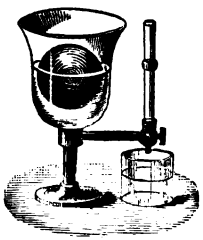


FIG. 81.

(*a.*) Place the tin vessel with a spout, mentioned in the last article, upon one scale-pan, and fill it with water, some of which will overflow through the spout. When the spout has ceased dripping, counterpoise the vessel of water with weights in the other scale-pan. Place a floating body on the water. This will

destroy the equilibrium, but water will overflow through the spout until the equilibrium is restored. This shows that the floating body has displaced its own weight of water.

EXERCISES.

1. How much weight will a *cu. dm.* of iron lose when placed in water?
2. How much weight would it lose in a liquid 13.6 times as heavy as water?
3. If the *cu. dm.* of iron weighs only 7780 *g.*, what does your answer to the 2d problem signify?
4. How much weight would a cubic foot of stone lose in water?
5. If 100 *cu. cm.* of lead weigh 1135 *g.*, what will it weigh in water?
6. If a brass ball weigh 83.8 *g.* in air and 73.8 *g.* in water, what is its volume?
7. If a brass ball weigh 83.8 oz. in air and 73.8 oz. in water, what is its volume?

Recapitulation.—In this section we have considered the Conditions of Liquids at Rest; the Equilibrium of liquids in Single and Communicating Vessels; the Water Supply of cities; the Equilibrium of Different Liquids in communicating vessels; Capillary Attraction and some of its Phenomena; Capillary Tubes; the quantity of a Fluid Displaced by an immersed solid; the Buoyancy of Fluids; Archimedes' Principle; several Explanations of Archimedes' Principle and its Experimental Verification; Floating Bodies.

SECTION III.

SPECIFIC GRAVITY.

241. What is Specific Gravity?—*The specific gravity of a body is the ratio between its weight and the weight of a like volume of some other substance taken as a standard.*

242. Standard of Specific Gravity.—The standard taken must be invariable. For solids and liquids, *the standard adopted is distilled water at a temperature of 4° C., or 39.2° F.* For aëriform bodies, the standard is air or hydrogen.

(*a.*) The water is to be distilled, or freed from all foreign substances, because the weight of a given quantity of water varies with the substances held in solution. It is to be at a fixed temperature because of the expansion by heat. The temperature above mentioned is that of water at its greatest density. In cases where air or hydrogen is taken as a standard, the additional condition of atmospheric pressure must, for obvious reasons, be recognized. The pressure to which all observations in this country are reduced is that recorded by 30 inches (760 *mm.*) of the barometer.

243. Elements of the Problem.—*For solids or liquids, the dividend is the weight of the given body; the divisor is the weight of the same bulk of water;* the quotient, which is an abstract number, is the specific gravity, and signifies that the given body is so many times heavier than the standard. The weight of the same bulk of water is found sometimes in one way and sometimes in another, but in *every case it is the divisor.* By grasping and keeping this idea, you will avoid much possible confusion. Of course, when any two of these three are given, the third can be found.

244. To Find the Specific Gravity of Solids.—The most common method of finding the specific gravity of a solid heavier than water, is to find the weight of the body in the air (= W), then suspend the body by a light thread and find its weight in water (= W′), and divide the weight of the body in air by the weight of the same bulk of water (§ 238, Archimedes' Principle).

$$Sp.\ Gr. = \frac{W}{W - W'}.$$

(*a*.) The method is illustrated by the following example:

Weight of substance in air = 58½ oz.
Weight of substance in water = 51 oz.
Weight of equal bulk of water = 7½ oz.
Specific gravity = 58½ oz. ÷ 7½ oz. = 7.8, *Ans.*

FIG. 82.

245. To Find the Specific Gravity of Solids Lighter than Water.—If the given body be lighter than water, fasten to it some body heavy enough to sink

it. Find the loss in weight of the combined mass when weighed in water. Do the same for the heavy body. Subtract the loss of the heavy body from the loss of the combined body. Divide the weight of the given body by this difference. (Show that this divisor is as indicated in § 243.) A modification of this method is to balance the sinker in water. Then attach to it the light substance in question, *e. g.*, a cork, and determine the buoyant effort of the cork, *i. e.*, the weight of its bulk of water. Divide as before.

(*a*.) The first method is illustrated by the following example:

(1.)	Weight of cork and iron in air	82.4 g.
(2.)	" " " " " water	52.4 g.
(3.)	" " water displaced by cork and iron	30. g.
(4.)	" " iron in air	77.8 g.
(5.)	" " " water	67.8 g.
(6.)	" " water displaced by iron	10. g.
(7.)	" " " " cork (3) − (6)	20. g.
(8.)	" " cork in air (1) − (4)	4.6 g.
(9.)	Specific gravity of the cork (8) ÷ (7)	.23
(10.)	" " " iron (4) ÷ (6)	7.78

246. To Find the Specific Gravity of Liquids.—The principle is unchanged. A simple method is as follows: Weigh a flask first empty; next, full of water; then, full of the given liquid. Subtract the weight of the empty flask from the other two weights; the results represent the weights of equal volumes of the given substance and of the standard. Divide as before. A flask of known weight, graduated to measure 100 or 1000 grams or grains of water is called a *specific gravity flask.* Its use avoids the first and second weighings above mentioned, and simplifies the work of division.

247. Another Simple Method.—The specific gravity of a liquid may be easily determined as follows: Find the loss of weight of any insoluble solid in water and in the given liquid.

From § 238, determine what these two losses represent. Divide as before. The solid used is called a *specific gravity bulb.*

Other methods are sometimes used, but as they depend upon the principles already explained, they need not be set forth here. Some of them will be illustrated in the problems.

248. To Find the Specific Gravity of Gases.—The specific gravity of an aëriform body is always found by comparing the weight of equal volumes of the standard (air or hydrogen) and of the given substance. The method is strictly analogous to the one first given for liquids. The air is removed from the flask with an air-pump—an instrument to be studied soon. The accurate determination of the specific gravity of gases presents many practical difficulties which cannot be considered in this place.

Note.—The weight of *any* solid or liquid (in grams per *cu. cm.*) represents its specific gravity. Bodies are commonly weighed in the air. But, in common with all other fluid bodies, *the air has weight and therefore* (§ 238) *diminishes the true weight* of all bodies thus weighed. This diminution is generally disregarded, but in certain delicate operations it must be carefully considered.

249. Hydrometers.—Instruments, called hydrometers or areometers, are made for the more convenient determination of specific gravity. They dispense with the use of the balance, an instrument requiring careful handling and preservation. Hydrometers are of two kinds:

(1.) *Hydrometers of constant volume,* as Nicholson's.

(2.) *Hydrometers of constant weight,* as Beaume's.

250. Nicholson's Hydrometer.—Nicholson's hydrometer is a hollow cylinder carrying at its lower end a basket *d*, heavy enough to keep the apparatus upright when floated on water. At the top of the cylinder is a vertical rod carrying a pan *a*, for holding weights, etc. The whole apparatus must be lighter than water, so that a certain weight (= *W*,) must be put into the pan to sink

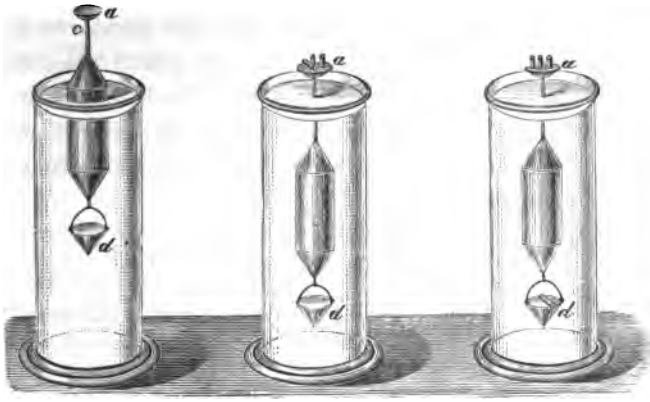


FIG. 83.

the apparatus to a fixed point marked on the rod (as c). The given body, which must weigh less than W, is placed in the pan, and enough weights ($= w$) added to sink the point c to the water line. It is evident that the weight of the given body is $W - w$. It is now taken from the pan and placed in the basket, when additional weights ($= x$) must be added to sink the point c to the water line.

$$Sp.\ Gr. = \frac{W - w}{x}.$$ (Why?)

251. Fahrenheit's Hydrometer.—Fahrenheit's Hydrometer is similar in form to Nicholson's, but is made of glass instead of metal, so that it may be used in any liquid. The basket is replaced by a bulb loaded with shot or mercury. The weight of the instrument ($= W$) is accurately determined. The instrument is placed in water,

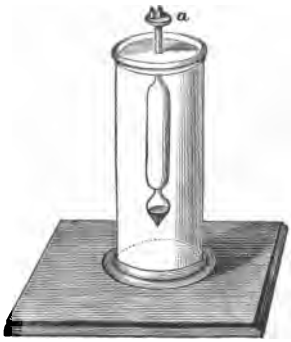


FIG. 84.

and a weight ($= w$), sufficient to sink the point c to the water line, is placed in the pan. The weight of water displaced by the instrument $= W + w$. The hydrometer is now removed, wiped dry, and placed in the given liquid. A weight ($= x$), sufficient to sink the hydrometer to c, is placed in the pan.

$$Sp.\ Gr. = \frac{W + x}{W + w}. \quad \text{(Why ?)}$$

Note.—A Nicholson's hydrometer may be used as a Fahrenheit's in any liquid which has no chemical action upon the metal of which it is made. Neither of these hydrometers gives results as accurate as those obtained by the methods previously given.

252. Constant Weight Hydrometers.—A hydrometer of constant weight consists of a glass tube near the bottom of which are two bulbs. The lower and smaller bulb is loaded with mercury or shot. The tube and upper bulb containing air, the instrument is lighter than water. The point to which it sinks when placed in pure water is generally marked zero. The tube is graduated above and below zero, the graduation being sometimes upon a piece of paper placed within the tube. As a long stem would be inconvenient, it is customary to have two instruments, one having zero near the top, for liquids heavier than water; the other having zero near the bulb, for liquids lighter than water. The scale of graduation is arbitrary, varying with the purpose for which the instrument is intended. These instruments are more frequently used to determine the degree of concentration or dilution of certain

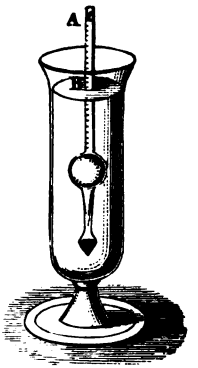


FIG. 85.

liquids, as acids, alcohols, milk, solutions of sugar, etc., than their specific gravities proper. According to their uses they are known as acidometers, alcoholometers, lactometers, saccharometers, etc. They all depend upon the principle that a floating body will displace its own weight of the liquid upon which it floats, and, consequently, a greater *volume* of light than of heavy liquids.

253. Tables of Reference.—(1.) Specific gravities of some solids:

Iridium.....23.00	Brass..... 8.38	Marble (statuary).2.83
Platinum.....22.069	Iron (bar).....7.78	Anthracite Coal..1.80
Gold (forged)...19.36	Tin (cast).....7.29	Bituminous Coal.1.25
Lead (cast).....11.35	Iron (cast).....7.21	Ice (melting)..... .92
Silver (cast)....10.47	Zinc (cast).....6.86	Pine..... .65
Copper (cast)... 8.79	Flint Glass.....3.33	Cork..... .24

(2.) Specific gravities of some liquids:

Mercury.....13.6	Nitric Acid.....1.22	Turpentine..... .87
Sulphuric Acid.. 1.84	Milk.....1.03	Alcohol..... .8
Chlorhydric Acid 1.24	Sea Water.....1.026	Ether..... .72

(3.) Specific gravities of some gases: (Barometer = 760 *mm.*; Temperature = 32° F. or 0° C.)

AIR = STANDARD.	HYDROGEN = STANDARD.
Iodohydric Acid.....4.41	Iodohydric Acid.....64
Carbonic Acid 1.52	Carbonic Acid..... 22
Oxygen.....1.1	Oxygen.....16
Air.....1.0	Air 14.5
Nitrogen..... .97	Nitrogen..... ... .14
Hydrogen..... .069	Hydrogen..... 1

Note.—The weight of a cubic foot of any solid or liquid is equal to 62.421 lbs. avoirdupois multiplied by its specific gravity.

The weight of a cubic centimeter of any solid or liquid is equal to 1 gram multiplied by its specific gravity.

The weight of a liter (or *cu. dm.*) of any solid or liquid is equal to 1 *Kg.* multiplied by its specific gravity.

The tables above give only *average* densities. Any given specimen may vary from the figures there given.

EXERCISES.

Note.—Be on the alert to recognize Archimedes' Principle in disguise. Consider the weight of water 62½ lbs. per cubic foot.

The numbers obtained for the right hand column may be either *plus* or *minus*; the former sign denotes weight in the fluid; the latter, the load it could support in the fluid.

No.	Weight in Air.	Weight in Water.	Loss of Weight in Water.	Spec. Grav.	Volume.	ANY FLUID.	
						Sp. Gr. of	Weight in
1	1500 lbs.	1000 lbs.	?	?	? cu ft.	1.5	?
2	5000 oz.	?	1500 oz.	?	?	?	2000 oz.
3	?	1875 g.	?	2	?	1.8	?
4	?	9375 g.	?	?	?	1.5	4687.5 g.
5	?	?	?	7.5	300 cu. cm.	2.5	?
6	?	1125 lbs.	?	?	?	3	875 lbs.
7	?	?	?	?	8 cu. ft.	13.6	2700 lbs.
8	?	?	?	6.86	5 cu. dm.	13.6	?
9	1 Kg.	?	?	1	?	?	200 g.
10	?	?	?	2.88	10 cu. ft.	.8	?

11. A bone weighs 2.6 ounces in water and 6.6 ounces in air; what is its specific gravity?

12. A body weighing 453 g. weighs in water 429.6 g.; what is its specific gravity?

13. A piece of metal weighing 52.35 g. is placed in a cup filled with water. The overflowing water weighed 5 g. What was the specific gravity of the metal?

14. (*a.*) A solid weighing 695 g. loses in water 83 g.; what is its specific gravity; (*b*) how much would it weigh in alcohol of specific gravity 0.792?

15. A 1000 grain bottle will hold 708 grains of benzoline. Find the specific gravity of the benzoline.

16. A solid which weighs 2.4554 oz. in air, weighs only 2.0778 oz. in water. Find its specific gravity.

17. A specimen of gold which weighs 4.6764 g. in air loses 0.2447 g. weight when weighed in water. Find its specific gravity.

18. A ball weighing 970 grs., weighs in water 895 grs., in alcohol 910 grs.; find the specific gravity of the alcohol.

19. A body loses 25 grs. in water, 23 grs. in oil, and 19 grs. in alcohol. Required the specific gravity of the oil and the alcohol.

20. A body weighing 1536 g. weighs in water 1283 g.; what is its specific gravity?

21. Calculate the specific gravity of sea water from the following data:

Weight of bottle empty			3.5305 g.
" "	filled with distilled water		7.6722 g.
" "	"	sea "	7.7849 g.

22. Determine the specific gravity of a piece of wood from the following data: Weight of wood in air, 4 g.; weight of sinker, 10 g.; weight of wood and sinker under water 8.5 g.; specific gravity of sinker, 10.5.

23. A piece of a certain metal weighs 3.7395 g. in air; 1.5780 g. in water; 2.2896 g. in another liquid. Calculate the specific gravities of the metal and of the unknown liquid.

24. Find the specific gravity of a piece of glass if a fragment of it weigh 2160 grains in air, and 1511½ grains in water.

25. A lump of ice weighing 8 lbs. is fastened to 16 lbs. of lead. In water the lead alone weighs 14.6 lbs. while the lead and ice weigh 13.712 lbs. Find the specific gravity of the ice.

26. A piece of lead weighing 600 g., weighs 545 g. in water and 557 g. in alcohol. (*a.*) Find the sp. gr. of the lead; (*b*) of the alcohol. (*c.*) Find the bulk of the lead.

27. A person can just lift a 300 pound stone in the water; what is his lifting capacity in the air (specific gravity of stone = 2.5)?

In the next three examples, the weight of the empty flask is not taken into account.

28. A liter flask holds 870 g. of turpentine; required the sp. gr. of the turpentine.

29. A liter flask, containing 675 g. of water, on having its remaining space filled with fragments of a mineral, was found to weigh 1487.5 g.; required the specific gravity of the mineral.

30. A liter flask was four-fifths filled with water; the remaining space being filled with sand the weight was found to be 1350 g.; required the specific gravity of the sand.

31. A weight of 1000 grs. will sink a certain Nicholson's hydrometer to a mark on the rod carrying a pan. A piece of brass plus 40 grs. will sink it to the same mark. When the brass is taken from the pan and placed in the basket, it requires 160 grs. in the pan to sink the hydrometer to the same mark on the rod. Find the specific gravity of the brass.

32. A Fahrenheit's hydrometer, which weighs 2000 grs., requires 1000 grs. in the pan to sink it to a certain depth in water. It requires 3400 grs. in the pan to sink it to the same depth in sulphuric acid. Find the specific gravity of the acid.

33. A certain body weighs just 10 g. It is placed in one of the scale-pans of a balance together with a flask full of pure water. The given body and the filled flask are counterpoised with shot in the other scale-pan. The flask is removed, and the given body placed therein, thus displacing some of the water. The flask being still quite full is carefully wiped and returned to the scale-pan, when it is found that there is not equilibrium. To restore the equilibrium, it is necessary to place 2.5 grs. with the shot. Find the specific gravity of the given body.

34. The volume of the earth is 1,082,842,000,000,000 cu. Km. Calculate its weight on the supposition that its average density is 5.6604.

35. A bottle holds 2545 mg. of alcohol (sp. gr. = 0.8095); 42740 mg. of mercury; 5829 mg. of sulphuric acid. Calculate the specific gravities of the mercury and of the alcohol.

36. A piece of cork weighing 2.3 g. was attached to a piece of iron weighing 38.9 g., both were found to weigh in water 26.2 g., the iron alone weighing 33.9 g. in water. Required the specific gravity of the cork.

37. A piece of wood weighing 300 grs. has tied to it a piece of lead weighing 600 grs.; weighed together in water they weigh 472.5 grs. The specific gravity of lead being 11.35, (*a*) what does the lead weigh in water; (*b*) what was the specific gravity of the wood?

38. Calculate the specific gravity of a mineral water from the following data:

Weight of a bottle empty	14.1256 g.
" " filled with distilled water	111.1370 g.
" " " " mineral "	111.7050 g.

39. A Fahrenheit's hydrometer weighs 618 grs. It requires 93 grs. in the pan to sink it to a certain mark on the stem. When wiped dry and placed in olive oil it requires only 31 grs. to sink it to the same mark. Find the specific gravity of the oil.

40. A platinum ball weighs 330 g. in air, 315 g. in water and 303 g. in sulphuric acid. Find the specific gravities (*a*) of the ball; (*b*) of the acid. (*c*.) What is the volume of the ball?

41. A hollow ball of iron weighs 1 Kg. What must be its least volume to float on water?

42. A piece of cork weighing 30 g. in air, was attached to 10 cu. cm. of lead. Loss of both in water = 1.59 g. Required the specific gravity of the cork.

43. A body whose specific gravity = 2.8, weighs 37 g. Required its weight in water.

44. What would a cubic foot of coal (sp. gr. = 2.4) weigh in a solution of potash (sp. gr. = 1.2)?

45. A platinum ball (sp. gr. = 22) weighing 300 g. in air will weigh how much in mercury (sp. gr. = 13.6)?

46. 500 cu. cm. of iron, specific gravity 7.8, floats on mercury; with what force is it buoyed up?

47. An areometer weighing 600 grs. sinks in water displacing a volume $= v$; in a certain acid, displacing a volume $= \frac{9}{10} v$; find the specific gravity of the acid.

Recapitulation.—In this section we have considered the Definition of Specific Gravity; the Standards agreed upon; the Two Elements in specific gravity problems; the Rule for finding the sp. gr. of Solids heavier than Water; the same for Solids lighter than Water; the same for Liquids; the same for Gases; the construction and methods of using Hydrometers; Tables of specific gravities, and some of the uses that may be made of them.

SECTION IV.

HYDROKINETICS.

254. Velocity of Spouting Liquids.—If a vessel having apertures in the side, similar to the one represented in Fig. 86, be filled with water, the liquid will escape from each of the apertures, but with different velocities. Were it not for the resistance of the air, friction, and the effect of the falling particles, the water issuing at V would ascend to the level of the water in the vessel; *i. e.*, the initial velocity of the water at V would carry it through the vertical distance Vh. But when equal verti-

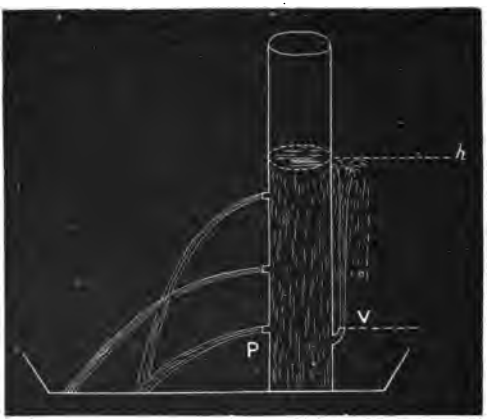


FIG. 86.

cal distances are passed over, the initial velocity of an ascending body is the same as the final velocity of a falling body. (§ 132.) Hence, the velocity of the water as it issues at V is the same that it would acquire in freely falling the vertical distance $h\,V$. This velocity is caused by lateral pressure. This lateral pressure will be the same at P, which is at the same distance below the level of the liquid. Therefore, the velocity at P will equal the velocity at V. Hence the following law: *The velocity of a stream flowing from an orifice is the same as that acquired by a body freely falling from a height equal to the head of the liquid.*

(*a*.) The *head* is the vertical distance from the centre of the orifice to the surface of the liquid.

(*b*.) With what velocity will water issue from an orifice 144.72 ft. below the surface of the liquid?

$$S = \tfrac{1}{2}gt^2 \qquad (\S\ 128\ [3].)$$
$$144.72 = 16.08t^2 \qquad \therefore\ 9 = t^2.$$
$$3 = t.$$
$$v = gt. \qquad (\S\ 128\ [1].)$$
$$v = 32.16 \text{ ft.} \times 3 = 96.48 \text{ ft.} \quad \textit{Ans.}$$

(*c.*) In the solution above we were obliged to find the number of seconds that would be required for a body to fall a distance equal to the head, before we could use the formula for the velocity. It is desirable, if possible, to shorten this circuitous process from two stages to one. This we may do as follows:

$$S = \tfrac{1}{2}gt^2 \qquad \therefore \quad t = \sqrt{\frac{2S}{g}}$$

Substituting this value of t in the formula, $v = gt$,

$$v = g\sqrt{\frac{2S}{g}} = \sqrt{2gS}$$

But h (the head) $= S$. Substituting this value of S in the last equation, we have, for the velocity of streams issuing from orifices, the following formula:

$$v = \quad (\sqrt{2gh} = \sqrt{64.32h} =) \quad 8.02\sqrt{h}.$$

The value of g being taken in feet, h and v must represent feet also.

(*d.*) With what velocity will water issue from an orifice under a head of 144.72 feet?

$$v = 8.02\sqrt{h}$$

$$v = 8.02\sqrt{144.72} = 8.02 \times 12.03 = 96.48, \text{ the number of feet.}$$

255. Orifice of Greatest Range.—The path of a stream spouting in any other than a vertical direction is the curve called a parabola (§ 135). The range of such a stream will be the greatest when it issues from an orifice midway between the surface of the liquid and the level of the place where the stream strikes. Streams flowing from orifices equidistant above and below this orifice of greatest range will have equal ranges. (See Fig. 86.) The range, in any such case, may be calculated by the laws of projectiles.

(*a.*) Given an aperture four feet below the surface and 20 ft. above the point where the water strikes, to find the range of the jet.

$$v = 8.02\sqrt{h} = 8.02 \times 2 = 16.04 \text{ ft. per second.}$$

$$S = \tfrac{1}{2}gt^2$$

$$20 = 16.08t^2 \qquad \therefore \quad t = 1.11 + \text{ sec.}$$

$$\text{Range} = 16.04 \text{ ft.} \times 1.11 = 17.8044 \text{ ft.}$$

256. Volume Discharged under a Constant Head.—*To find the volume discharged in a given time under a constant head, multiply the area of the orifice by the velocity, and this product by the number of seconds.*

(*a*.) Suppose that as soon as the water escapes it freezes and retains the form and size given it by the aperture. It will then be evident that the water escaping in one second will form a prism whose section will be the area of the orifice and whose length will be the same as the velocity of the jet. The product of these dimensions will give the volume of the imaginary prism, one of which is formed every second. Care must be had that the velocity and the dimensions of the orifice are of the same denomination. The *theoretical* result computed as above directed, will exceed the amount actually discharged. Why? (See Appendix E.)

257. The Flow of Liquids through Horizontal Pipes.—When liquids from a reservoir are made to flow through pipes of considerable length, *the discharge is far less than that due to the head.* This is chiefly owing to the friction of the liquid particles against the sides of the pipe. A horizontal inch-pipe 200 feet long will not discharge much, if any, more than a quarter as much water as a very short pipe of the same size, the head being the same. Frequent and abrupt bends in the pipe retard the flow, and must be provided for by an increase in the size of the pipe, or an increase of pressure.

258. The Flow of Rivers.—The friction of a stream against its solid bed fortunately retards the velocity of the water. Otherwise the velocity of the current at the mouth of a river, whose head is elevated 1000 feet above its mouth, would be about 170 miles per hour. Such a current would be disastrous beyond description.

The ordinary river current is from three to five miles per hour.

259. The Flow of Liquids through Vertical Pipes.—Liquids flowing freely through vertical pipes *exert no lateral pressure.* The liquid will not wholly fill the tube, but will be surrounded by a thin film of air. These air particles will be dragged down by the adhesion of the falling liquid. If a small tube *t* be inserted near the top of the vertical pipe a current of air will be forced through it and down the pipe. This air current may be utilized for blow-pipe and other purposes. With a long discharge pipe, the force with which the air is drawn through *t* may be used to remove the air from a vessel, *R.* The apparatus then becomes a Sprengel's or Bunsen's air-pump. (§§ 290, 291.)

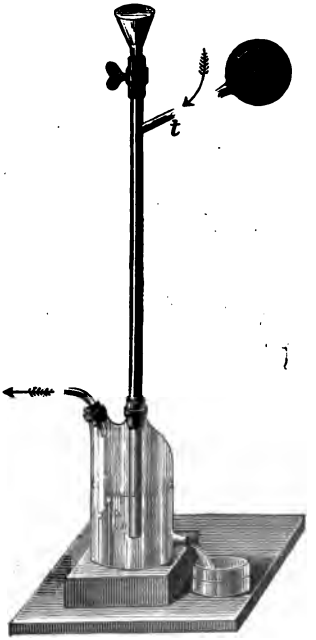


FIG. 87.

260. Water-power.—Water may be used to turn a wheel and thus move machinery by its weight, the force of the current, or both. The wheels thus turned are of different kinds; the availability of any one being determined by the nature of the water supply and the work to be done.

261. The Overshot Wheel.—In the overshot wheel the water falls into buckets at the top, and by its weight, aided by the force of the current, turns the wheel. As the buckets are gradually inverted, the water is emptied, and the load thus removed from the other side of the wheel. Such wheels require but little water but a great fall. It is said that they have been made nearly 100 feet in diameter. The water is led to the top of the wheel by a *sluice, GH.*

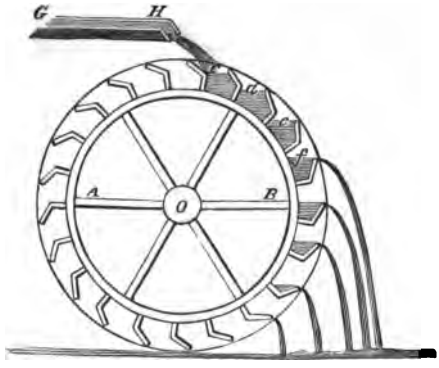


FIG. 88.

262. The Breast Wheel.—In the breast wheel, the water acts upon float boards fixed perpendicular to the circumference. The stream being received at or near the level of the axis, both the weight of the water and the force of the current may be turned to account.

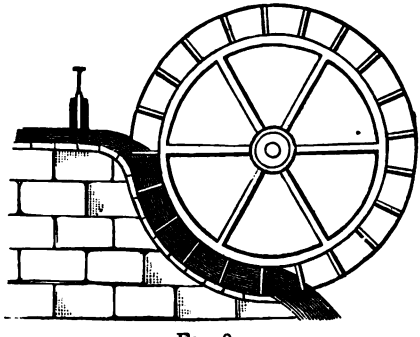


FIG. 89.

263. The Undershot Wheel.—In the undershot wheel, the stream strikes, near the bottom of the

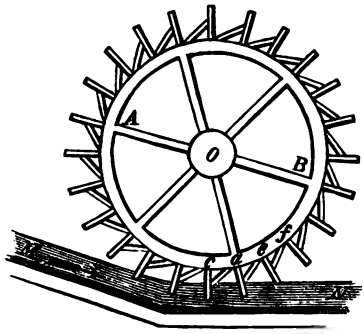


FIG. 90.

wheel, against a few float boards, which are more or less submerged, and thus acts by the force of the current.

Note.—In point of efficiency, these wheels rank in the order above given, utilizing from 80 to 25 per cent. of the total energy of the stream.

264. The Reaction Wheel. — The reaction wheel is well illustrated by Barker's Mill, represented in Fig. 91. It consists essentially of a vertical tube connecting with horizontal tubular arms at the bottom. The ends of these arms are bent in the same direction, and are open at their ends. The apparatus is supported on a pivot so as to move freely. Water is poured into the upper end of the vertical cylinder, and escapes through the openings *a* and *b*, at the bent ends of the arms. The wheel revolves in a direction

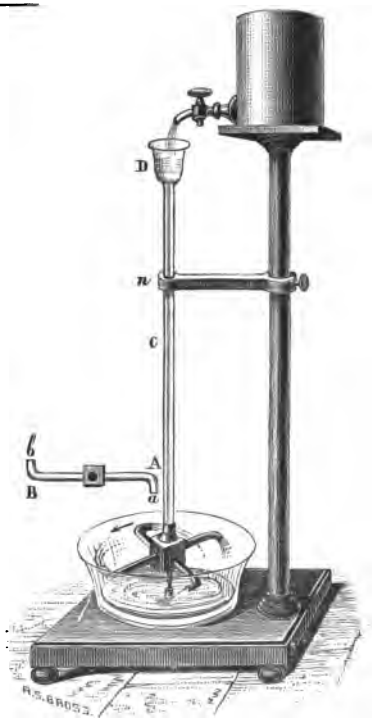


FIG. 91.

opposite to that of the water jets. The principle involved was explained in § 230.

265. The Turbine Wheel.—The turbine wheel, of which there are many varieties, is the most effective water-wheel yet known, utilizing, in some cases, 85 per cent. of the total energy of the stream.

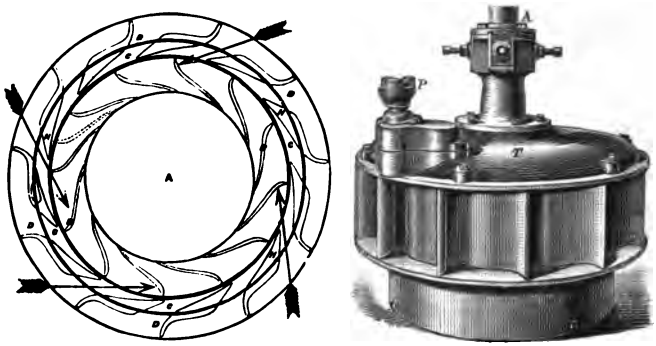


FIG. 92.

(*a.*) Fig. 92 represents one form in perspective and in horizontal section through the centre of the wheel and case complete. The wheel *B* and the enclosing case *D* are placed on the floor of a penstock wholly submerged in water, under the pressure of a considerable head. The water enters, as shown by the arrows, through openings in *D*, which are so constructed that it strikes the buckets of *B* in the direction of greatest efficiency. After leaving the buckets, the "dead-water" escapes from the central part of the wheel, sometimes by a vertical draft tube, best made of boiler-iron. The weight of the water in this tube increases the velocity with which the water strikes the buckets. A central shaft, *A*, is carried by the wheel and communicates its motion to the machinery above. The wheel itself rests upon a central pivot carried by cross-arms from the bottom of the outer case. The case *D* is covered with a top *T*, which protects the wheel from the vertical pressure of the water. The axis of the wheel passes through the centre of this cover. The openings by which the water passes to the wheel are called chutes. Sometimes a cylindrical collar, *C*, is placed between

the wheel *B* and the outer case *D*. This collar, called a register gate, may be turned about its axis by the action of a pinion, *P*, upon teeth placed upon the circumference of *C*. By means of the register gate, the size of the chute may be reduced and the amount of water used thus diminished. The water passages, to and from the wheel, should be of such a size that the velocity of the water running through them shall not exceed one and a half feet per second.

266. Lateral Pressure of Running Water.—If water could flow through a pipe unimpeded ($v = 8.02\sqrt{h}$), there would be no lateral pressure. But as the velocity is lessened by friction and other causes, this lateral pressure begins to be felt; when the velocity is destroyed, lateral pressure has its full force again. Thus, a pipe is less likely to burst when carrying running water than when filled with water at rest.

267. Bursting Pressure.—If a current of water flowing in a pipe be suddenly stopped, much of its momentum will be changed to lateral or bursting pressure. This takes place whenever the faucet of a water-pipe is suddenly closed. Plumbers frequently leave the ends of such pipes in a vertical position so that a quantity of air may be confined between the closed end of the pipe and the water below. This air by its elasticity acts as a pad or cushion, thus lessening the suddenness of the shock and preventing accidents.

(*a*.) This principle is practically applied in the "hydraulic ram," a contrivance by which the impulse of running water when suddenly checked may be used to raise a part of the water through a vertical distance greater than the head.

EXERCISES.

1. A stream of water issues from an orifice at the bottom of a vessel containing water 170 feet deep. Give the velocity of the stream?

2. How much water issues in one hour from the orifice in the bottom of a vessel in which the water always stands 12 feet high, the orifice being $\frac{1}{10}$ of a square inch?

3. How much water per hour will be delivered from an orifice of 2 inches area, 25 feet below the surface of a tank kept full, no allowance being made for friction, etc.?

4. From an orifice, water spouts with a velocity of 96.48 feet. What is the head?

5. An orifice is 16.08 feet above a horizontal floor. Water spouts to the distance of 80.4 feet. Required the head.

6. Determine the formula for the velocity of spouting liquids, using meters instead of feet. *Ans.* $v = 4.427\sqrt{h}$.

7. A stream of water issues from an orifice under a head of 25 meters. Find the velocity of the stream.

8. How many liters of water will flow through an opening of 10 sq. cm. in 20 seconds, the head being kept at 36 m.? *Ans.* 531.24 l.

9. How long will it take for 442,700 cu. cm. of water to escape through a hole 1 centimeter square and 100 meters below the surface of the liquid?

10. How long will it take to empty a tank having a base 3 m. by 4 m. the water being 5 m. deep, by means of a sq. cm. hole in its bottom?

Recapitulation.—In this section we have considered the Velocity of spouting liquids; the orifice of Greatest Range; the method of computing the Volume discharged by an orifice when the Head is constant; the flow of liquids through Pipes and Rivers; the uses of Water-power; the five kinds of Water-wheels; the Lateral Pressure of running water; the Bursting Pressure when the current is suddenly stopped.

Review Questions and Exercises.

1. (*a.*) Define Physics. (*b.*) Define and illustrate four universal properties of matter.

2. (*a.*) What is the difference between momentum and energy? (*b.*) Find the momentum and (*c.*) kinetic energy of a 15 lb. ball moving fifty feet per second.

3. (*a.*) Give the third law of motion and illustrate it. (*b.*) Give the law of reflected motion.

4. (*a.*) What would a 1470 lb. ball weigh at 10,000 miles above the earth? (*b.*) Give the law that you use.

5. (*a.*) How far will a body fall during the fourth second? (*b.*) How far in four seconds? (*c.*) What will be its final velocity?

6. The crank of an endless screw whose threads are an inch apart describes a circuit of 72 inches. The screw acts on the toothed edge of a wheel whose circumference is 90 inches and that of its axle 12 inches. On the axle is wound a cord which acts on a set of pulleys three in each block, the force of which pulleys is exerted on the wheel of a wheel and axle, the wheel being 4 feet and the axle 8 inches in diameter. What weight on the axle will be lifted by a power of 30 lbs. at the crank, allowing for a loss of one-third by friction?

7. (*a.*) What is the length of a pendulum making 25 vibrations a minute? (*b.*) How many vibrations are made per minute by a pendulum 25 inches long?

8. (*a.*) What is a horse-power? (*b.*) A unit of work? (*c.*) If a two horse-power engine can just throw 1056 lbs. of water to the top of a steeple in 2 minutes, what is the height of the steeple?

9. (*a.*) What are the laws of machines? (*b.*) The facts concerning friction? (*c.*) What is a lever? (*d.*) Figure a lever of each kind. In a lever of the second kind the power is $4\frac{1}{2}$, the weight is $40\frac{1}{2}$, the distance of the power from the weight is 18 in. (*e.*) What is the length of the lever? (*f.*) What the length of the short arm?

10. If the diameters of the wheel and axle of a wheel and axle are respectively 60 in. and 6 in., and the power 150 lbs., what weight will be sustained?

11. (*a.*) Draw a system of 3 fixed and 2 movable pulleys. (*b.*) If the power be 90 and the friction one-third, what weight can be raised?

12. (*a.*) A weight of 12 pounds, hanging from one end of a five foot lever considered as having no weight, balances a weight of 8 pounds at the other end. Find how far the fulcrum ought to be moved for the weights to balance when each is increased by two pounds. (*b.*) Give the law for the screw?

13. A capstan, 14 inches in diameter, has four levers each 7 feet long. At the end of each lever a man is pushing with a force of 42 pounds. What is the effect produced, one-fourth of it being lost by friction?

CHAPTER V.

PNEUMATICS.

SECTION I.

THE ATMOSPHERE AND ATMOSPHERIC PRESSURE.

268. What is Pneumatics?—*Pneumatics is that branch of Physics which treats of aeriform bodies, their mechanical properties, and the machines by which they are used.*

269. Tension of Gases.—*However small their quantity, gases always fill the vessels in which they are held.* If a bladder or India rubber bag, partly filled with air, and having the opening well closed, be placed under the receiver of an air-pump, the bladder or bag will be fully distended, as shown in the figure, when the air surrounding the bladder is pumped out. The flexible walls are *pushed out* by the air confined within. This tendency is called elastic force or *tension.*

FIG. 93.

270. The Type.—As water was, for obvious reasons, taken as the type of liquids, so *atmospheric air will be*

taken as the type of aeriform bodies. Whatever mechanical properties are shown as belonging to air may be understood as belonging to all gases.

271. The Aerial Ocean.—Air is chiefly a mixture of two gases, oxygen and nitrogen, in the proportions of one to four by volume. It is believed that the atmosphere at its upper limit presents a *definite surface* like that of the sea; that disturbing causes produce waves there just as they do on the sea, but that, by reason of greater mobility and other causes, the waves on the surface of this aërial ocean are much larger than any ever seen on the surface of the liquid ocean. The depth of this aërial ocean has been variously estimated at from fifty to two hundred miles.

272. Weight of Air.—Being a form of matter, air has weight. This may be shown by experiment. A hollow globe of glass or metal, having a capacity of several liters and provided with a stop-cock, is carefully weighed on a delicate balance. The air is then removed from the globe by an air-pump, the stop-cock closed, and the empty globe weighed carefully. The second weight will be less than the first, the difference between the two being the weight of the air removed. Under ordinary conditions a cubic inch of air weighs about 0.31 grains; a liter of air weighs about 1.293 *g.*, being thus about $\frac{1}{770}$ as heavy as water. (See Appendix G.)

273. Atmospheric Pressure.—Having weight, such a quantity of air must exert a great pressure upon the surface of the earth and all bodies found there. This atmospheric pressure necessarily decreases as we ascend from the earth's surface. For any surface, at any elevation, the upward, downward, or lateral pressure may be

computed in the same way as for liquids (§§ 226, 228 and 231). Owing to the great compressibility of aëriform bodies, the lower layers of the atmosphere are much more dense than the upper ones, but density and pressure alike are constant in value throughout any horizontal layer. The weight of a column of air one inch square extending from the sea-level to the upper limit of the atmosphere is about fifteen pounds; a similar column, a *cm.* square, weighs about 1 *Kg.* We express this by saying that *the atmospheric pressure at the sea-level is fifteen pounds to the square inch,* or 1 *Kg.* to the *sq. cm.* Several illustrations of atmospheric pressure will be given after we have considered the air-pump.

274. Torricelli's Experiment.—The intensity of this pressure may be measured as follows:—Take a glass tube a yard long, about a quarter of an inch in internal diameter. Close one end and fill the tube with mercury. Cover the other end with the thumb or finger and invert the tube, placing the open end in a bath of mercury. Upon removing the thumb, the mercury will sink, oscillate, and finally come to rest at a height of about 30 inches, or 760 *mm.*, above the level of the mercury in the bath. This historical experiment was first performed in 1643, by Torricelli, a pupil of Galileo. The apparatus used, when properly graduated, becomes a barometer.

FIG. 94.

275. What Supports the Mercury Column? —To answer this very important question, consider the horizontal layer of mercury molecules in the tube at the level of the liquid in the bath. Under ordinary circumstances, they would hold their position by virtue of the tendency of liquids to seek their level. But in this case, they hold it against the downward pressure caused by the weight of the mercury column above, which is equivalent to fifteen pounds to the square inch. Being in a condition of equilibrium, they must be acted upon by an upward pressure of fifteen pounds to the square inch. It is evident that the pressure of the mercury in the bath is not able to do this work, its powers being fully tasked in supporting the mercury in the tube up to the level of the particular molecules now under consideration. This upward pressure then must be due to some force acting upon the surface of the mercury, and transmitted undiminished by that liquid. *The only force, thus acting, is atmospheric pressure,* which is thus measured. The original column of thirty-six inches fell because its weight was greater than the opposing force. As it fell, its weight diminished, continuing to do so until an equality of opposing forces produced equilibrium. (See Appendix H.)

276. Pascal's Experiments.—Pascal confirmed Torricelli's conclusions by varying the conditions. He had the experiment repeated on the top of a mountain and found that the mercury column was three inches shorter, showing that as the weight of the atmospheric column diminishes, the supported column of mercury also diminishes. He then took a tube forty feet long, closed at one end. Having filled it with water, he inverted it over a

water bath. *The water in the tube came to rest at a height of 34 feet.* The water column was 13.6 times as high as the mercury column, but as the specific gravity of mercury is 13.6, the weights of the two columns were equal. Experiments with still other liquids gave corresponding results, all of which strengthened the theory that the supporting force is due to the weight of the atmosphere, and left no doubt as to its correctness.

277. Pressure Measured in Atmospheres.—A gas or liquid which exerts a force of fifteen pounds upon a square inch of the restraining surface is said to exert a pressure of one atmosphere. A pressure of 60 pounds to the square inch, or 4 *Kg.* to the *sq. cm.*, would be called a pressure of four atmospheres.

FIG. 95.

278. The Accuracy of a Barometer.—The accompanying figure represents the simplest form of the barometer. The instrument's accuracy depends upon the purity of the mercury, the accuracy of measuring the vertical distance from the level of the liquid in the cistern to that in the tube, and the freedom of the space at the top of the tube from air and moisture. In delicate observations allowance must be made for differences of temperature. In technical language, "The barometric reading is corrected for temperature."

279. The Utility of a Barometer.—This instrument's efficiency depends upon the fact that variations in atmospheric pres-

sure produce corresponding variations in the height of the barometer column. It is used to determine the height of places above the sea-level, foretell storms, etc. When, at a given place, the "barometer falls," a storm is generally looked for. Sometimes the storm does not come, and faith in the accuracy of the instrument is shaken. But, in fact, the barometer did not announce a coming storm; *it did proclaim a diminution of atmospheric pressure from some cause or other.* Its declarations are perfectly reliable; inferences from those declarations are subject to possible error.

280. The Aneroid Barometer.—This instrument consists of a cylindrical box of metal with a top of thin, elastic, corrugated metal. The air is removed from the box. The top is pressed inward by an increased atmospheric pressure; whenever the atmospheric pressure diminishes, it is pressed outward by its own elasticity aided by a spring beneath. These movements of the cover are transmitted and multiplied by a combination of delicate levers. These levers act upon an index which is thus made to move over a graduated scale. Such barometers are much more easily portable than the mercurial instruments. They are made so delicate that they show a difference in atmospheric pressure when transferred from an ordinary table to the floor. Their very delicacy involves the necessity for careful usage or frequent repairs.

FIG. 96.

281. The Baroscope.—Air, having weight, has buoyant power. The Principle of Archimedes (§ 238) applies to gases as well as to liquids. From this it follows that the weight of a body in air is not its true weight, but that it is less than its true weight by exactly the weight of

the air it displaces. This principle is illustrated by the baroscope, which consists of a scale-beam supporting two bodies of very unequal size (as a hollow globe and a lead ball), which balance one another in the air. If the apparatus thus balanced in the air be placed under the receiver of an air-pump, and the air exhausted, the globe will descend, thus seeming to be heavier than the lead ball which previously balanced it. Is the globe actually heavier than the lead, or not?

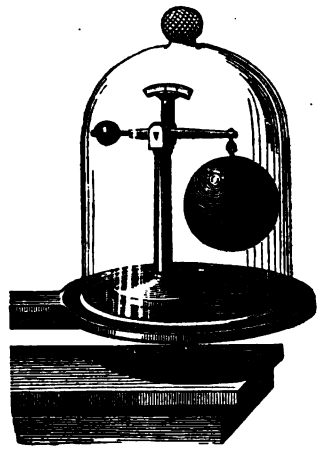


FIG. 97.

EXERCISES.

1. Give the pressure of the air upon a man the surface of whose body is 14½ square feet.

2. A soap-bubble has a diameter of 4 inches; give the pressure of the air upon it. (See Appendix, Note *a*.)

3. What is the weight of the air in a room 30 by 20 by 10 feet?

4. What will be the total pressure of the atmosphere on a decimeter cube of wood when the barometer stands 760 mm.?

5. How much weight does a cubic foot of wood lose when weighed in air?

6. (*a*.) What is the pressure on the upper surface of a Saratoga trunk 2½ by 3½ feet? (*b*.) How happens it that the owner can open the trunk?

7. When the barometer stands at 760 mm. what is the atmospheric pressure per sq. cm. of surface? *Ans.* 1033.6 g.

Note.—In round numbers, atmospheric pressure at the sea-level is called 15 lbs. to the sq. in., or 1 kilogram to the sq. cm.

8. A certain room is 10 m. long, 8 m. wide and 4 m. high. (*a.*) What weight of air does it contain? (*b.*) What is the pressure upon its floor? (*c.*) Upon its ceiling? (*d.*) Upon each end? (*e.*) Upon each side? (*f.*) What is the total pressure upon the six surfaces? (*g.*) Why is not the room torn to pieces?

9. An empty toy balloon weighs 5 g. When filled with 10 *l.* of hydrogen, what load can it lift? (See Appendix, G.)

Recapitulation.—In this section we have considered the definitions of Pneumatics and Tension; the Aerial Ocean in which we live; the mechanical Properties of Air; the weight of air giving rise to Atmospheric Pressure; a famous experiment by Torricelli, and the explanation thereof; Pascal's experiments and the conclusion they confirmed; the Barometer; the Aneroid barometer; the Baroscope.

SECTION II.

THE RELATION OF TENSION AND VOLUME TO PRESSURE.

282. Tension of Gases.—If a glass flask, provided with a stop-cock, be closed under an atmospheric pressure which supports a mercury column of 30 inches, the atmospheric pressure from without is exactly balanced by the tension (§ 269) of the air within. If it be closed under a barometric pressure of 28 inches, this equality of the two pressures will continue. If the flask be closed when the surrounding air is subjected to a pressure of two or three atmospheres, the equality will still continue. In none of these cases will the glass be subjected to any strain because

of the air within or without. *The tension of aeriform bodies supports the pressure exerted upon them, and is equal to it.*

283. Experimental Illustrations of Tension.—(1.) The tension of confined air is well illustrated by the common pop-gun. It is also well illustrated by the common experiment with bursting squares. These "squares" are made of *thin* glass, are about two or three inches on each edge, and are hermetically sealed under the ordinary atmospheric pressure. The tension of the air within, acting with equal intensity against the atmospheric pressure from without, the frail walls remain uninjured. When, however, the "square" is placed under the receiver of an air-pump and the external pressure removed, the tension of 15 pounds to the square inch is sufficient to burst the walls outward.

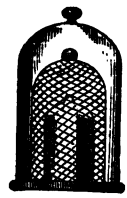


FIG. 98.

(2.) Half fill a small bottle with water, close the neck with a cork through which a small tube passes. The lower end of this tube should dip into the liquid; the upper end should be drawn out to a smaller size. Apply the lips to the upper end of the tube, and force air into the bottle. Notice, describe, and explain what takes place.

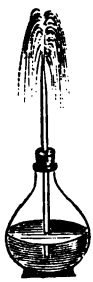


FIG. 99.

(3.) Place the bottle, arranged as above described, under the receiver of an air-pump, and exhaust the air from the receiver. Water will be driven in a jet from the tube. Explain.

284. Mariotte's Law.—*The temperature remaining the same, the volume of a given quantity of gas is inversely as the pressure it supports.*

285.—Experimental Verification of Mariotte's Law.—This law may be experimentally verified with Mariotte's tube. It consists of a long glass tube bent as shown in Fig. 100, the long arm being open and the short arm closed. A small quantity of mercury is poured into the tube, so that the two mercurial surfaces are in the

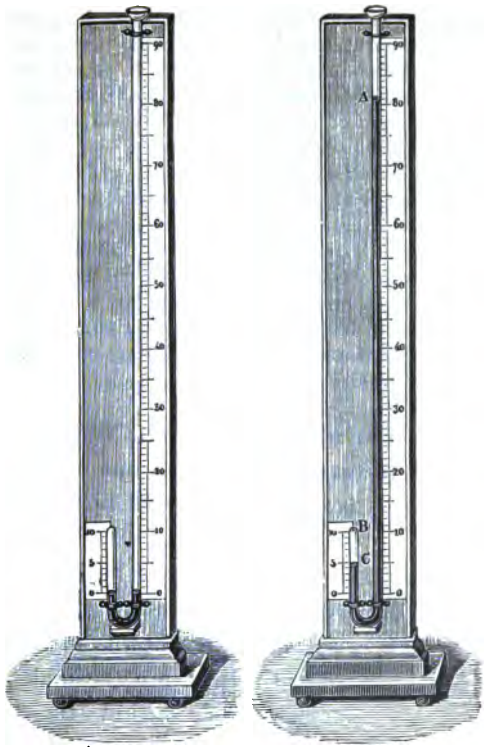


FIG. 100.

same horizontal line. By holding the tube nearly level, bubbles of air may be passed into the short arm or from it until the desired result is secured. The air in the short arm will then be under an ordinary atmospheric pressure. As more mercury is poured into the long arm the confined air will be compressed.

(*a.*) **When the vertical distance between the levels of the mercury in the two arms is one-third the height of the barometric column at the time and place of the experiment, the pressure upon the confined air will be $\frac{4}{3}$ atmospheres; the tension of the confined air**

just supports this pressure and must therefore be ½ atmospheres. The volume of the confined air is only ½ what it was under a pressure of one atmosphere. If more mercury be poured into the long arm until the vertical distance between the two mercurial surfaces is one-half the height of the barometric column, the pressure and tension will be ⅔ atmospheres; the volume of the confined air will be ⅓ what it was under a pressure of one atmosphere. When mercury has been poured into the long arm until the vertical distance *CA* is equal to the height of the barometric column, the pressure and tension will be two atmospheres, and the volume of the confined air will be one-half what it was under a pressure of one atmosphere. The law has been thus "verified" up to 27 atmospheres, notwithstanding which it is not considered rigorously exact. The deviation from exactness, however, can be detected only by measurement of great precision.

286. The Rule Works both Ways.—The law holds good for pressures of less than one atmosphere, for rarefied air as well as for compressed air. To show that this is true, nearly fill a barometer tube with mercury and invert it over a mercury bath held in a glass tank as shown in the figure. Lower the tube into the tank until the mercury levels within the tube and without it are the same. The air in the tube is confined under a pressure of one atmosphere. Note the volume of air in the barometer tube. Raise the tube until this volume is doubled. The vertical distance between the two mercurial surfaces will be found to be half the height of the barometric column. The confined portion of air, which is now subjected to the pressure of half an atmosphere, occupies twice the space it

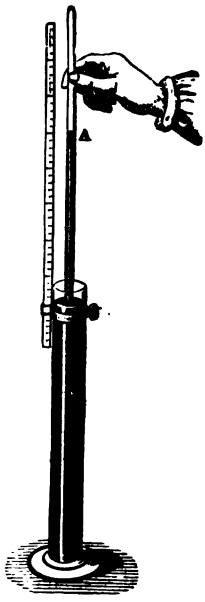


FIG. 101.

did under a pressure of one atmosphere. And so on. It may be more convenient to have the barometer tube open at both ends, the upper end being closed with the thumb or finger before lifting.

287. A Summing Up.—From the foregoing experiments we have a right to conclude that *the density and tension of a given quantity of gas are directly, and that its volume is inversely, as the pressure exerted upon it.* Representing the volumes of the same quantity of gas by V and v, and the corresponding pressures and densities by P and p, D and d, our conclusion may be algebraically expressed as follows:

$$\frac{V}{v} = \frac{p}{P} = \frac{d}{D}.$$

EXERCISES.

1. Under ordinary conditions, a certain quantity of air measures one liter. Under what conditions can it be made to occupy (*a.*) 500 cu. cm.? (*b.*) 2000 cu. cm.?

2. Under what circumstances would 10 cu. inches of air at the ordinary temperature weigh 31 grains?

3. Into what space must we compress (*a.*) a liter of air to double its tension? (*b.*) A liter of hydrogen?

4. A barometer standing at 30 inches is placed in a closed vessel. How much of the air in the vessel must be removed that the mercury may fall to 15 inches?

5. A vertical tube, closed at the lower end, has at its upper end a frictionless piston which has an area of one sq. inch. The weight of this piston is five pounds. (*a.*) What is the tension of the air in the tube? (*b.*) If the piston be loaded with a weight of ten pounds, what will be the tension?

6. When the barometer stands at 28½ inches, the mercury is at the same level in both arms of a Mariotte's tube. The barometer rises and the difference in the two mercurial surfaces of the Mariotte's tube is half an inch. (*a.*) In which arm is it the higher? (*b.*) What is the height of the barometer?

7. Eight grains of air are enclosed in a rigid vessel of such size that the tension is 16½ pounds per square inch. What will be the tension if three more grains of air be introduced?

Recapitulation.—In this section we have considered the Equality of tension and pressure, with several Experimental Illustrations; Mariotte's Law; the Verification of that law for Compressed and for Rarefied Gases; a brief Conclusion from the teachings of these experiments.

SECTION III.

AIR-PUMPS.—LIFTING AND FORCE-PUMPS.—SIPHON.

288. The Air-Pump.—*The air-pump is an instrument for removing air from a closed vessel.* The essential parts are shown in section by Fig. 102; the complete instrument, as made by Ritchie, is represented by Fig. 103.

The closed vessel *R* is called a receiver. It fits accurately upon a horizontal plate, through the centre of which is an opening communicating, by means of a bent tube, *t*, with a cylinder, *C*. An accurately fitting piston moves in this cylinder. At the junction of the bent tube with the cylinder, and in the piston, are two valves, *v* and *v'*, opening from the receiver but not toward it. The tension of the air in *R*, and the pressure of the air upon the valves, are equal. When the piston is raised, *v'* closes and the atmospheric pressure is removed from *v*. The tension of the air in *R* opens *v*. By virtue of its power of indefinite

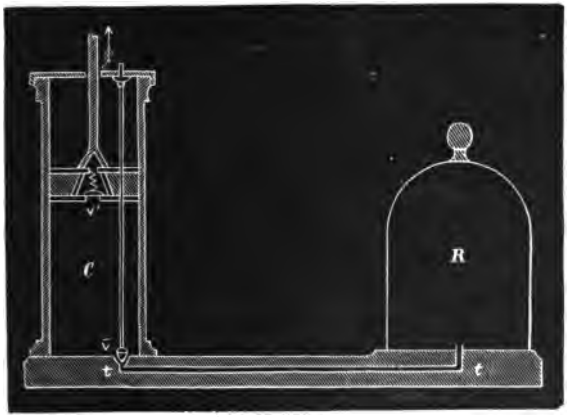


FIG. 102.

FIG. 103.

expansion, the air which, at first, was in R and t, now fills R, t, and C. When the piston is pushed down, v closes, v' opens, and the air in C escapes from the apparatus.

(*a.*) The lower valve v is sometimes supported, as shown in Fig. 102, by a metal rod which passes through the piston. This rod works tightly in the piston, and is thus raised when the piston is raised, and lowered when the piston is lowered. A button near the upper end of this rod confines its motion within very narrow limits, allows v to be raised only a little, and compels the piston, during most of the journeys to and fro, to slide upon the rod instead of carrying the rod with it.

289. Degrees and Limits of Exhaustion.—Suppose that the capacity of R is four times as great as that of C. (The capacity of t may be disregarded.) Suppose that R contains 200 parts of air (*e. g.*, 200 grains), and C, 50 parts. After lifting the piston the first time, there will be 160 grains ($= 200 \times \frac{4}{5}$) of air in R, and 40 grains ($200 \times \frac{1}{5}$) in C. After the second stroke there will be 128 grains [$= 160 \times \frac{4}{5} = 200 \times \frac{4}{5} \times \frac{4}{5} = 200 \times (\frac{4}{5})^2$] of air in R, and 32 grains in C. After n upward strokes, $200 \times (\frac{4}{5})^n$ grains of air will remain in the receiver. Evidently, therefore, *we never can, by this means, remove all the air which R contains,* although we might continually approach a perfect vacuum, if this were the only obstacle. It requires an exceedingly good air-pump to reduce the tension of the residual air to $\frac{1}{100}$ inch of mercury. This limit is due to several causes, among which may be mentioned the leakage at different parts of the apparatus, the air given out by the oil used for lubricating the piston, and the fact that there is a space at the bottom of the cylinder untraversed by the piston.

290. Sprengel's Air-Pump.—This instrument is used to apply the principles set forth in § 259 to the ex-

haustion of small receivers. The liquid used is mercury. The vertical pipe, below the arm t (Fig. 87), must be longer than the barometer column (six feet is a common length), and have a diameter of not more than $\frac{1}{10}$ inch. The mercury is admitted by large drops, which, filling the pipe, act as valves and in their fall force out successive quantities of air before them.

(*a.*) With such an instrument, it requires about half an hour to exhaust a half liter receiver, but the average result attainable is a tension of about one-millionth atmosphere or 0.00003 inch of mercury. By this means a tension of only $\frac{1}{1500000}$ atmosphere has been secured. The mercury acts as a dry, frictionless, perfectly fitting, self-adjusting piston. Special precautions must be taken to make the connection air-tight. The only work of the operator is to carry the mercury from the cistern at the foot of the fall tube to the funnel at the top.

291. Bunsen's Air-Pump.—In Bunsen's air-pump the principle is the same, but the liquid used is water, and the length of the vertical pipe at least thirty-four feet. Such an air-pump may be easily provided in a laboratory where the waste-pipe of the sink has the necessary vertical height. The tube t (see Fig. 87) being connected with the receiver, has its free end inserted in the waste-pipe a little way below the sink. A stream of water properly regulated, flowing into the sink, completes the apparatus.

292. The Condenser.—*The condenser is an instrument for compressing a large amount of air into a closed vessel.* It differs from the air-pump, chiefly, in that *its valves open toward the receiver.* The cylinder is generally attached directly to the stop-cock of the receiver. Its operation will be readily understood. Sometimes the upper valve, v', instead of

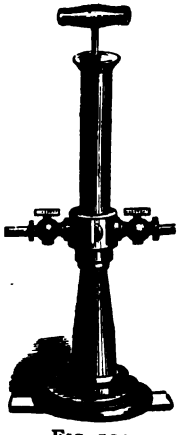


FIG. 104.

being placed in the piston, is placed in a tube opening from the side of the cylinder below the piston. By connecting this lateral tube with a reservoir containing any gas, the gas may be drawn from the reservoir and forced into the receiver. When thus made and used, the instrument is called a *transferrer* (Fig. 104).

Note.—The pupil will notice that in the case of the air-pump, the condenser, the transferrer, and the lifting and force pumps to be subsequently considered, the valves open in the direction in which the fluid is to move.

293. Experiments. — A person having an air-pump has the means of performing almost numberless experiments, some amusing and all instructive. Other experiments, which may be performed without such apparatus, have been purposely deferred until now. The pupil should explain each experiment.

(1.) The pressure of the atmosphere, which is transmitted in all directions, may be illustrated by filling a tumbler with water, placing a slip of thick paper over its mouth and holding it there while the tumbler is inverted; the water will be supported when the hand is removed from the card.

(2.) Plunge a small tube, or a tube having a small opening at the lower end, into water, cover the upper end with the finger and lift it from its bath. The water is kept in the tube by atmospheric pressure. Remove the finger, and the downward pressure of the atmosphere, which was previously cut off, will counterbalance the upward pressure and the water will fall by its own weight. Such a tube, called a *pipette*, is much used for transferring small quantities of liquids from one vessel to another. The pipette is often graduated.

(3.) *The "Sucker"* consists of a circular piece of thick leather with a string attached to its middle. Being soaked thoroughly in water it is firmly pressed upon a flat stone to drive out all air from between the leather and the stone. When the string is pulled

gently there is a tendency toward the formation of a vacuum between the leather and the stone. The stone is now pushed upward with a force of 15 lbs. for every square inch of its lower surface (§ 273.) It is pressed *downward* with a force of 15 lbs. upon each square inch of its upper surface *not covered by the "sucker."* The downward atmospheric pressure upon the leather is sustained by the string. This difference between the upward and downward atmospheric pressures *upon the stone* may be greater than the gravity of the stone. Then we say that the stone is pulled up by the "sucker;" in reality the stone is *pushed up* by the air.

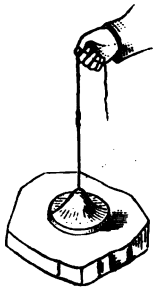


FIG. 105.

(4.) *The hand-glass* is a receiver open at both ends. The lower end fits accurately upon the plate of the air-pump. (It is well to smear the plate with tallow in this and similar experiments.) The hand is to be placed over the other end. When the pump is worked, the pressure of the atmosphere is felt, and the hand can be removed only by a considerable effort. The appearance of the palm of the hand at the end of this experiment is due to the tension of the air within the tissues of the hand.

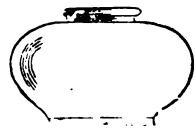


FIG. 106.

(5.) Repeat the experiment described in § 269.

(6.) Over the upper end of a cylindrical receiver, tie tightly a wet bladder, and allow it to dry. Then exhaust the air. The bladder will be forced inward, bursting with a loud noise.

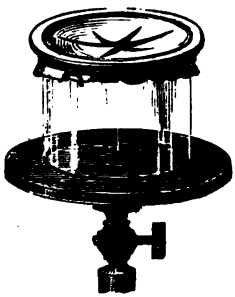


FIG. 107.

(7.) Replace the bladder with a piece of thin india-rubber cloth. Exhaust the air. The cloth will be pressed inward and nearly cover the inner surface of the receiver. The hand-glass, used in experiment (4), will answer for the two experiments last given, by placing the small end upon the pump-plate.

(8.) Review the experiments mentioned in § 283.

(9.) *The "fountain in vacuo"* consists of a glass vessel through the base of which passes a tube terminating in a jet within, and provided with a stop-cock and screw without. By means of the screw it may be attached to the air-pump and the

air exhausted. Remove the air, close the stop-cock, place the lower end of the tube in water, open the stop-cock; a beautiful fountain will be produced (Fig. 109).

(10.) *The mercury shower* apparatus consists of a cup through the bottom of which passes a plug of oak or other porous wood. Place the cup upon the *hand-glass* with a tumbler below; pour some mercury into the cup; exhaust the air, and the atmospheric pressure will force the mercury through the pores of the wood.

FIG. 108.

FIG. 109.

(11.) *The weight-lifter* (Fig. 110) is an apparatus by means of which the pressure of the atmosphere may be made to lift quite a heavy weight. It consists of a stout glass cylinder, *C*, supported by a frame and tripod. Within the lower part of the cylinder is a closely fitting piston from which the weight is hung. A brass plate is ground to fit accurately upon the top of the cylinder. This plate is perforated and a flexible tube, *B*, connects the cylinder with an air-pump. When the air is exhausted from the cylinder, the atmospheric pressure on the lower surface of the piston raises the piston and supported weight the length of the cylinder.

FIG. 110.

(12.) *The Magdeburg hemispheres* are made of metal. They are hollow, and generally three or four inches in diameter. Their edges are provided with projecting lips which fit one over the other. These edges fit one another air-tight; the lips prevent them from

moving *sidewise*. The edges being greased and placed together, the air is exhausted from the hollow globe through a tube provided with a stop-cock and screw. When the air has been pumped out, close the stop-cock, remove the hemispheres from the pump, and screw a convenient handle upon the lower hemisphere, the upper one being provided with a permanent handle. It will be found that a considerable force is necessary to pull the hemispheres asunder. This force is equal to the atmospheric pressure upon the circular area inclosed by the edges of the hemispheres. If this area be ten square inches it will require a pull of 150 pounds to separate the hemispheres.

FIG. 111.

(13.) Partly fill two bottles with water. Connect them by a bent tube which fits closely into the mouth of one and loosely into the mouth of the other. Place the bottles under the receiver and exhaust the air. Water will be driven from the closely stoppered bottle into the other. Readmit air to the receiver and the water thus driven over will be forced back.

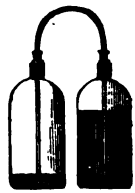


FIG. 112.

294. The Lifting-Pump.—The lifting-pump consists of a cylinder or barrel, piston, two valves, and a suction pipe, the lower end of which dips below the surface of the liquid to be raised. The arrangement is essentially the same as in the air-pump. As the piston is worked, the air below it is gradually removed. The downward pressure on the liquid in the pipe being thus removed, *the transmitted pressure of the atmosphere, exerted upon the surface of the liquid, pushes the liquid up through*

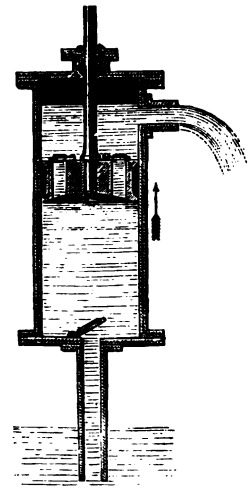


FIG. 113.

the suction pipe and the lower valve into the barrel. When the piston is again pressed down, the lower valve closes, the reaction of the water opens the piston valve, the piston sinking below the surface of the liquid in the barrel. When next the piston is raised, it lifts the water above it toward the spout of the pump. At the same time, atmospheric pressure forces more liquid through the suction pipe into the barrel.

295. Notes and Queries.—The cistern or well containing the liquid must not be cut off from atmospheric pressure, *i. e.*, must not be made air-tight. Why? For water pumps, the suction pipe must not be more than 34 feet high. Why? Owing to mechanical imperfections chiefly, the practical limit of the water pump is 28 vertical feet. As the lifting of the liquid above the piston does not depend upon atmospheric pressure, water may be raised from a very deep well by placing the barrel, with its piston and valves, within 28 feet of the surface of the water, and providing a vertical discharge pipe to the surface of the ground. The piston-rod may work through this discharge pipe. Deep mines are frequently drained by using a series of pumps, one above the other, the handles (levers) of which are worked by a single vertical rod. The lowest pump empties the water into a reservoir, from which the second pump lifts it to a second reservoir, and so on.

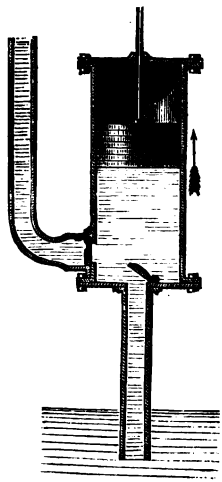


FIG. 114.

296. The Force-Pump.—In the force-pump, the piston is generally made solid, *i. e.*, without any valve. The upper valve is placed in a discharge pipe which opens from the barrel at or near its bottom. When the piston is raised, water is forced into the barrel by atmospheric pressure. When the piston is forced down, the suction pipe valve is closed, the water

being forced through the other valve into the discharge pipe. When next the piston is raised, the discharge pipe valve is closed, preventing the return of the water above it, while atmospheric pressure forces more water from below into the barrel.

297. The Air-Chamber of a Force-Pump.—Water will be thrown from such a pump in spurts, corresponding to the depressions of the piston. *A continuous flow is secured by connecting the discharge pipe with an air-chamber.* This air-chamber is provided with a delivery pipe, the lower end of which terminates below the surface of the water in the air-chamber. When water is forced into the air-chamber, it covers the mouth of the delivery pipe, and compresses the air confined in the chamber. This diminution of volume of the air is attended by a corresponding increase of tension (§ 284), which soon becomes sufficient to force the water through the delivery pipe in a continuous stream.

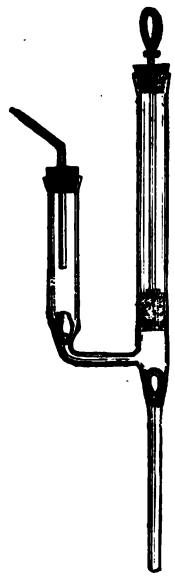


FIG. 115.

298. The Siphon.—The siphon consists of a bent tube, open at both ends, having one arm longer than the other. It is used to transfer liquids from a higher to a lower level, especially in cases where they are to be removed without disturbing any sediment they may contain. It may be first filled with the liquid, and then placed with the shorter arm in the higher vessel, care being had that the liquid does not escape from the tube until the opening

C is lower than mn, the surface of the liquid; or it may be first placed in position, and the air removed by suction at the lower end; whereupon, by the pressure of the atmosphere, the fluid will be forced up the shorter arm and fill the tube. In either case a constant stream of the liquid will flow from the upper vessel until the surface line mn is brought as low as the opening in the shorter arm, or, if the liquid be received in another vessel, until the level is the same in the two vessels.

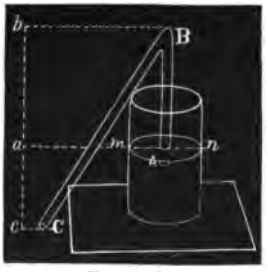


FIG. 116.

299. Explanation of the Siphon.—This action of the siphon may be thus explained: For convenience, suppose that the sectional area of the tube is one inch, that the downward pressure of the water in the arm AB is one pound, and that the downward pressure of the water in the arm BC is three pounds. The upward pressure in the tube at A will equal the atmospheric pressure on each inch of the surface mn outside the tube *minus* the downward pressure of one pound, *i. e.*, $(15 - 1 =)$ 14 pounds. On the other side, there is at C the upward atmospheric pressure of 15 pounds, from which must be taken the downward pressure of the water in BC, leaving a resultant upward pressure of 12 pounds at C. The upward pressure at A being two pounds greater than that at C, determines the flow of the water ABC. The greater the difference between ba and bc, the greater the velocity of the stream.

300. Limitations.—If the downward pressure at A be equal to the atmospheric pressure, the liquid will not

flow. Therefore, *if the liquid be water, the height, ab, must be less than 34 feet;* if it be mercury, *ab* must be less than the mercury column of the barometer.

301. Intermittent Springs. — Occasionally a spring is found which flows freely for a time, and then ceases to flow for a time. Fig. 117 represents an underground reservoir, fed with water through fissures in the earth. The channel through which the water escapes

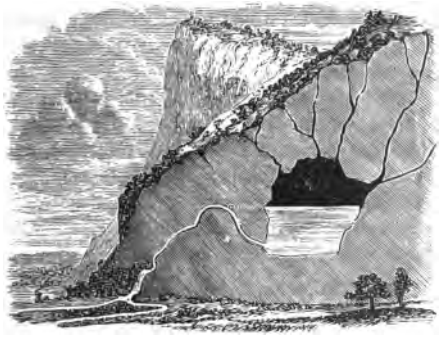


FIG. 117.

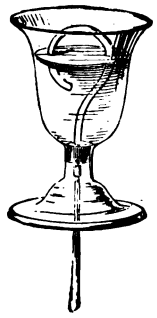


FIG. 118.

from this reservoir forms a siphon. The water escaping at the surface constitutes a spring. When the water in the reservoir reaches the level of the highest point in the channel, the siphon begins to act, and continues to do so until the water level in the reservoir falls to the mouth of the siphon. The spring then ceases to flow until the water has regained the level of the highest point of the siphon-like channel. This action is well illustrated by "Tantalus' Cup," represented in Fig. 118.

EXERCISES.

1. How high can water be raised by a *perfect* lifting-pump, when the barometer stands at 30 inches? (See § 253, [2].)

2. If a lifting-pump can just raise water 28 ft., how high can it raise alcohol having a specific gravity of 0.8?

3. Water is to be taken over a ridge 12.5 *m.* higher than the surface of the water. (*a.*) Can it be done with a siphon? Why? (*b.*) With a lifting-pump? Why? (*c.*) With a force-pump? Why?

4. How high will bromine stand in an exhausted tube, when mercury stands 755 *mm.*? (Sp. gr. of bromine = 2.96.)

5. If water rises 34 feet in an exhausted tube, how high will sulphuric acid rise under the same circumstances?

6. The sectional area of the piston of a "weight-lifter" being 15 sq. inches, what weight could the instrument raise?

7. If the capacity of the barrel of an air-pump is $\frac{1}{4}$ that of the receiver, (*a.*) what part of the air will remain in the receiver at the end of the fourth stroke of the piston, and (*b.*) how will its tension compare with that of the external air?

8. How high could a liquid with a sp. gr. of 1.35 be raised by a lifting-pump when the barometer stands 29.5 inches?

9. Over how high a ridge can water be continuously carried in a siphon, the minimum standing of the barometer being 69 *cm.*?

10. What is the greatest pull that may be resisted by Magdeburg hemispheres (*a.*) 4 inches in diameter? (*b.*) 8 *cm.* in diameter? (See Appendix, Note *a.*)

Recapitulation.—In this section we have considered the Air-pump; the Limits of Exhaustion attainable by the ordinary air-pump; Sprengel's and Bunsen's air-pumps; the Condenser and Transferrer; numerous Experiments pertaining to aëriform pressure and tension; the Lifting-pump; the Force-pump; the Siphon and Intermittent Springs.

Review Questions and Exercises.

1. Define (*a.*) Physics, (*b.*) Chemistry, (*c.*) Atom, (*d.*) Molecule, (*e.*) Solids, (*f.*) Liquids and (*g.*) Aëriform Bodies.

2. Define (*a.*) Inertia, (*b.*) Impenetrability and (*c.*) Hardness, illustrating each by examples.

3. (*a.*) Define Momentum and (*b.*) Energy. A body weighs 500 lbs., and has a velocity of 60 ft. per second; (*c.*) what is its momentum and (*d.*) what its energy? (*e.*) How would each be affected by doubling the weight? (*f.*) By doubling the velocity?

4. Give (*a.*) the facts and (*b.*) the laws of gravity. A body weighs 1440 lbs. at the surface of the earth; (*c.*) how far above the surface will its weight be 90 lbs.? (*d.*) What will it weigh 2200 miles below the surface?

5. (*a.*) What is a machine? (*b.*) What is a foot-pound? (*c.*) Tell how the advantage gained by a simple mechanical power is found; and (*d.*) show this by an illustration of your own. (*e.*) Explain the cause of friction.

6. (*a.*) What is a simple pendulum? (*b.*) What is an oscillation? (*c.*) How does a change of latitude change the number of vibrations? (*d.*) Why?

7. (*a.*) What is the length of a second's pendulum? (*b.*) What is the length of one vibrating $\frac{1}{3}$ seconds?

8. (*a.*) State the general law of machines, and (*b.*) illustrate it by means of the pulley.

9. (*a.*) What is the centre of gravity? (*b.*) How found?

10. (*a.*) Draw figures illustrating the position of parts in the different kinds of levers; (*b.*) make and solve a simple problem in each.

11. (*a.*) What is the relation which the length of a pendulum bears to its time of oscillation? (*b.*) Give the length of a pendulum beating once in $2\frac{1}{2}$ seconds.

12. (*a.*) Give the second and third laws of motion, and (*b.*) illustrate them.

13. A and B, at opposite ends of a bar 6 ft. long, carry a weight of 600 pounds suspended between them. A's strength being twice as great as B's, how far from A must the weight be suspended?

14. (*a.*) Give the formulas for falling bodies, (*b.*) translating them into common language. (*c.*) Give the same for bodies rolling freely down inclined planes. A body fell from a balloon one mile above the surface of the earth; (*d.*) in what time, and (*e.*) with what velocity would it reach the earth?

15. A ball thrown downward with a velocity of 35 feet per second reaches the earth in $12\frac{1}{2}$ seconds. (*a.*) How far has it moved, and (*b.*) what is its final velocity?

16. (*a.*) A bricklayer's laborer with his hod weighs 170 pounds; he puts into the hod 20 bricks weighing 7 pounds each; he then climbs a ladder to a vertical height of 30 feet. How many units of work does he? (*b.*) If he can do 158,100 units of work in a day, how many bricks will he take up the ladder in a day?

17. Define three accessory properties of matter.

18. How much weight will a cubic meter of any solid lose when weighed (*a.*) in hydrogen? (*b.*) in air? (*c.*) in carbonic acid gas?

19. Can you devise a plan by which an ordinary mercurial barometer may be used to measure the rarefaction secured by an air-pump?

20. (*a.*) Give the laws of liquid pressure, and (*b.*) find the pressure on one side of a cistern filled with water, 5 feet square and 12 feet high?

21. (*a.*) What is specific gravity? (*b.*) What the standard for liquids and solids? (*c.*) How is the sp. gr. of solids found?

22. Calculate the atmospheric pressure upon a man having a body surface of 16,000 *sq. cm.*

23. What is the upward pull of a balloon of 1,000 *cu. m.*, when filled with gas half as heavy as air, its own weight being 25 *Kg.*?

24. (*a.*) State Archimedes' principle. (*b.*) How may it be experimentally verified? (*c.*) In finding specific gravity, what is *always* the dividend and what is *always* the divisor? (*d.*) A specific gravity bulb weighs 38 *g.* in air, 28 *g.* in water, and 20 *g.* in an acid. Find the sp. gr. of the acid.

25. (*a.*) Describe an overshot water-wheel, and (*b.*) give a drawing.

26. (*a.*) Define the three kinds of equilibrium. (*b.*) Where is the centre of gravity in a ring? (*c.*) Why are lamps, clocks, etc., provided with heavy bases?

27. Find the weight in sulphuric acid (sp. gr. 1.75) of a piece of lead weighing 150 *g.*, and having a sp. gr. of 11.

28. A pendulum 1 meter long makes 40 oscillations in a given time; how long must a pendulum be to make 60 oscillations in the same time and at the same place?

29. (*a.*) Give Mariotte's law. (*b.*) How high could a fluid having a sp. gr. of 1.35 be raised in a common pump when the barometer stands at 29.5 inches?

30. Represent, by drawings in section, the essential parts of (*a.*) an air-pump, (*b.*) a lifting-pump, and (*c.*) a force-pump. (*d.*) Why does the water rise in the suction pipe of a lifting-pump? (*e.*) What is the *immediate* force that throws water in a steady stream from a force-pump?

31. Water flows from an orifice 25 feet below the surface of the water, and 144.72 feet above the level ground. Find the range of the jet.

32. State briefly, by diagram or otherwise, the distinguishing features of solid, liquid and aëriform bodies.

CHAPTER VI.

MAGNETISM AND ELECTRICITY.

SECTION I.

MAGNETS.

Note.—A desire to secure favorable atmospheric conditions for experiments in frictional electricity has determined the order in which the following branches of physics are taken up. In most places in this country, the school-year begins with September. In such cases, this chapter would probably be reached by January, during which month the atmosphere is generally dry. Under other circumstances, the consideration of these subjects would better be omitted until sound, heat, and light have been studied.

302. Natural Magnet.—The mineral called loadstone is the only known natural magnet. It is an ore of iron, composed of iron and oxygen. *If a piece of loadstone be rolled in iron filings, some of the filings will cling to the loadstone when it is removed.*

303. Artificial Magnets.—Artificial magnets are usually made of steel. They have all the properties of natural magnets, are more powerful and convenient. They are, therefore, preferable for general use. The most common forms are the *straight* or *bar* magnet and the *horseshoe* magnet. The first of these is a straight bar of

FIG. 119.

steel; the second is shaped like a letter U, the ends being thus brought near together, as shown in Fig. 119.

304. Distribution of Magnetic Force.—If a bar magnet be rolled in iron filings and then withdrawn, the filings cling to the ends of the bar but not to the middle. This peculiar form of attraction is not evenly

FIG. 120.

distributed throughout the bar. *It is greatest at or near the ends.* These points of greatest attraction are called the poles of the magnet.

305. Attraction between a Magnet and Ordinary Iron.—Bring either end of a bar magnet near the end of a piece of iron; the iron is attracted. Bring the same end of the magnet near the middle of the iron; the iron is attracted. Bring the same end of the magnet

near the other end of the iron; the iron is attracted. Repeat the experiments with the other end of the magnet; in each case the iron is attracted. From these experiments we have a right to conclude that *either pole of a magnet will attract ordinary iron.*

306. Attraction between Two Magnets.— Freely suspend three bar magnets, *A*, *B* and *C*, at some

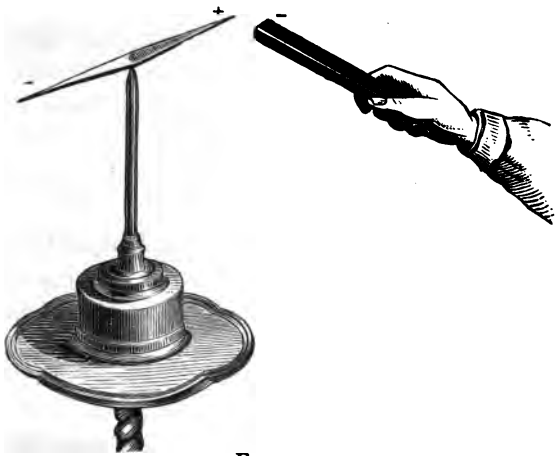


FIG. 121.

distance from each other. (Place each magnet in a stout paper stirrup supported by a cord; or place each upon a board or cork floating on water.) When they have come to rest, each will lie in a north and south line. Magnets are chiefly characterized by the property of attracting iron and this tendency to assume a particular direction of position when freely suspended. Mark the north end of each suspended magnet —, and the south end of each, +. (§ 317.)

(*a.*) Take the magnet *A* from its support, and bring its + end near the — end of *B* or *C*. Notice the attraction. (*b.*) Bring the + end

of *A* near the + end of *B* or *C*. Notice the repulsion. (*c*.) Bring the − end of *A* near the − end of *B* or *C*. Notice the repulsion. (*d*.) Bring the − end of *A* near the + end of *B* or *C*. Notice the attraction. (Fig. 121.) (*e*.) From experiment (*a*) we learned that the − ends of *B* and *C* were each attracted by the + end of *A*. Bring the − end of *B* near the − end of *C*. Notice that they now repel. (*f*.) From experiment (*b*) we learned that the + ends of *B* and *C* were each repelled by the + end of *A*. Bring the + end of *B* near the + end of *C*. Notice that they now repel. (*g*.) In similar manner show that the + end of *B* will attract the − end of *C*; that the − end of *B* will attract the + end of *C*.

From these experiments we have a right to conclude that *every magnet has two dissimilar poles; that like poles repel each other, but that unlike poles attract each other.*

Note.—In all of these experiments we deal with a cause capable of producing motion. Hence (§ 64), magnetism is a force.

307. Effect of Breaking a Magnet.—*If a magnet be broken, each piece becomes a magnet* with two poles and an equator of its own. These pieces may be repeatedly subdivided and each fragment will be a perfect

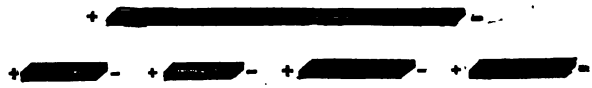


FIG. 122.

magnet. It is probable that every molecule has its poles, or *is polarized*, and that, could one be isolated, it would be a perfect magnet. We thus conceive a magnet as made up of molecules each of which is a magnet, the action of the molar magnet being due to the combined action of all the molecular magnets of which it is composed.

308. Theory of Magnetism.—For the explanation of the phenomena that we have noticed, the existence of two magnetic fluids *has been imagined.* The fluid whose resultant effects are manifested at the + end of the magnet is called the positive fluid;

in the same way the other is called the negative fluid. It is imagined that each of these two fluids repels its like and attracts its opposite; that neither can exist without the other, every magnet possessing equal quantities of both; that, owing to their mutual attraction, they tend to combine in or around each molecule and thus neutralize each other; that they may be separated by a force greater than their mutual attraction, and made to arrange themselves in a certain position in or about the molecules to which they belong, but that they cannot be removed from them. In this way we imagine to our minds the formation of a magnet by bringing together rows of polarized molecules, whose similar poles are turned in the same direction. The magnetic separation thus imagined is represented in Fig. 123. The effects of the opposite polar fluids neutralize each other at the middle of the bar, but are manifested at opposite ends of the bar. (§ 335.) (Appendix I.)

FIG. 123.

309. A Hypothetical Theory.—The theory sketched in the preceding paragraph has value because it connects the various phenomena of magnetism. But we must remember that it is only a hypothesis, and is seriously doubted by scientific men. Neither it nor its companion, the Theory of Electric Fluids, can be received unsuspectingly until they can connect the phenomena of magnetism and electricity one with the other, and both of them with the phenomena of heat and light. Although as yet they cannot do this, we may use them with profit unless we allow ourselves to accept them with a confidence that blinds our sight to the approach of something better.

310. Magnetic and Diamagnetic Substances.—Substances that are attracted by a magnet are called *magnetic; e.g.*, iron or steel and nickel. Substances that are repelled by a magnet are called *diamagnetic; e. g.*, bismuth, antimony, zinc, tin, mercury, lead, silver, copper, gold and arsenic. Of these, iron is by far the most magnetic, while bismuth is the most diamagnetic. The magnetic properties of iron or steel are easily shown; diamagnetic properties require a powerful magnet for satisfactory illustration.

311. Magnetic Induction.—If a bar of soft iron be brought near one of the poles of a strong magnet, it becomes, for the time being, a magnet. The poles of the

temporary magnet will be opposite to those of the permanent magnet. The molecules of the iron seem to be polarized by the force of the magnet when brought within the limited range of that force. The combined fluid is separated in each molecule, because the fluid acting at the pole of the magnet attracts its opposite and repels its like, and this separating influence is greater than the mutual attraction of the two fluids thus torn asunder. The iron is said to be magnetized by *induction*. If the distance between the iron and the magnet be diminished, the inductive influence is thereby increased. Actual contact is not necessary, but when the iron and the magnet touch, this inductive force is the greatest. This force, like other forms of attraction, varies inversely as the square of the distance (§ 100 [2]).

312. Illustrations of Magnetic Induction.—(*a.*) When a piece of soft iron, as a nail or ring, is brought near the end of a magnet, the molecules of the iron are polarized (*i. e.*, their magnetic fluids are separated), and the iron becomes a magnet for this reason. When the ring touches the magnet it will be supported. Bring a second ring near the first ring. The action of the first ring, which is a magnet now, polarizes the second ring and thus renders it a magnet also. Let it touch the first ring magnet and it will be supported. In this way quite a number of rings (Fig. 124) may be supported, each ring in turn being thus magnetized by its predecessor. Of course, the attractive and repulsive forces are continually weakening from the first to the last ring. Now support

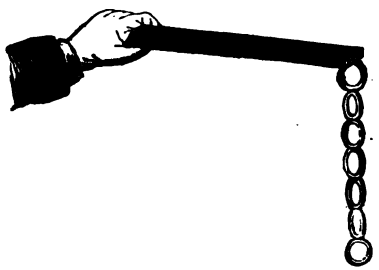


FIG. 124.

the upper ring upon your finger, and remove the magnet. The force that separated the fluids in the molecules of the first ring and held them apart is no longer present; those fluids, therefore, rush together. There is now no cause capable of holding apart the opposite fluids in the molecules of the second ring, and they consequently rush together; and so in the case of each ring.

(*b.*) Suspend an iron key from the positive end of a bar magnet. The key is inductively magnetized, the relation of its poles to each other and to the magnet being as shown in Fig. 125. A second

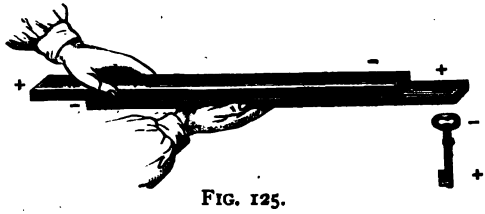


FIG. 125.

bar magnet of about the same power, with its poles opposite, is moved along the first magnet. When the − end of the second magnet comes over the key, the key drops. The + pole of the lower magnet attracted the − and repelled the + of the key. The − pole of the upper magnet had an opposite effect, and as the two magnets were of the same power, or nearly so, the separating influence became less than the mutual attraction of the opposite fluids, which consequently reunited. This experiment goes to show that when a magnetic body is attracted by a magnet, the *attraction is preceded by polarization.*

313. Magnetic Curves.—The inductive influence of a magnet upon iron is not affected by the interposition of any non-magnetic body. Over a good bar magnet place a piece of card-board, upon which sprinkle iron filings; tap the card-board lightly. The "magnetic curves" (Fig. 126) thus formed are very interesting and instructive. The filings in any one of these curves are temporary magnets with adjoining poles opposite and therefore attracting. By using two bar magnets placed side by side, *first,* with like poles near each other, and, *secondly,* with unlike

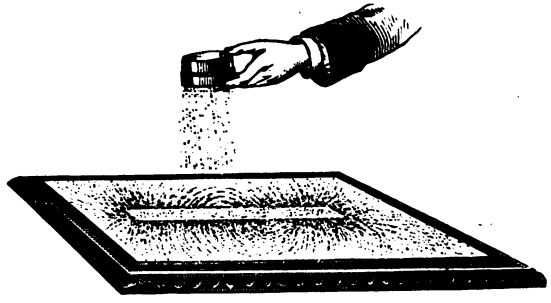


FIG. 126.

poles near each other, their combined effect on the iron filings may be easily observed.

314. Magnetic Needles.—A bar magnet may be supported by balancing it upon a pivot, by suspending it by a fine untwisted thread, by floating it upon water by means of a cork, and in several other ways. *A small bar magnet suspended in such a manner as to allow it to assume its chosen position is a magnetic needle.*

FIG. 127.

FIG. 128.

(*a.*) If it be free to move in a horizontal plane it is a horizontal needle; *e. g.*, the mariner's or the surveyor's compass (Fig. 127). It will come to rest pointing nearly north and south. If the magnet be free to move in a vertical plane it constitutes a vertical or dipping needle (Fig. 128). Two magnets fastened to a common axis but having their poles reversed constitute

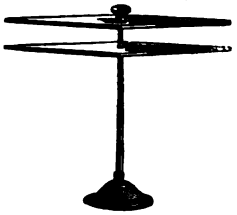


FIG. 129.

an astatic needle (Fig. 129). An astatic needle assumes no particular direction with respect to the earth. (§ 391.)

315. Terrestrial Magnetism.—If a small dipping needle be placed over the — end of a bar magnet, the needle will take a vertical position with its + end down (Fig. 130). As the needle is moved toward the other end of the bar it turns from its vertical position. When over the

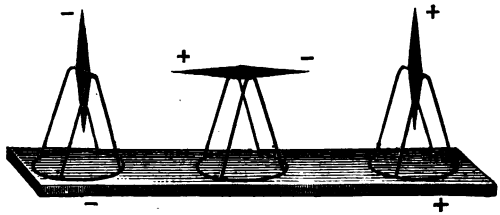


FIG. 130.

neutral line, the needle is horizontal. As it approaches the + end of the magnet the needle again becomes vertical, but the — end of the needle is drawn down. If a dipping needle be carried from far southern to far northern latitudes it will act in a similar way. These facts seem to teach that *the earth is a great magnet with magnetic poles near its geographical poles.* The magnetic pole in the northern hemisphere was found in 1832 by Capt. Ross. It is a little north and west of Hudson's Bay, in latitude 70° 05′ N., and longitude 96° 45′ W. A place in the southern hemisphere has been found where the needle is *nearly* vertical.

316. The Earth's Inductive Influence.—That the earth is really a magnet is further shown by its induc-

tive influence. *An iron bar placed in the position assumed by the dipping needle and struck a sharp blow on the end becomes polarized.* The magnetic influence of the bar may be tested by moving a small magnetic needle along its length, and noticing that one end of the bar attracts one end of the needle and the other the other end. A steel poker which has usually stood in a nearly vertical position may thus be shown to have acquired magnetism. (See Appendix J.)

317. Names of Magnetic Poles.—We have now learned to regard the earth as a huge magnet, with one pole in the northern hemisphere and one in the southern. Since unlike poles attract each other, it follows that *the earth's magnetic pole situated in the northern hemisphere is opposite to the end of a magnetic needle that points to the north.* From this fact, great confusion of nomenclature has arisen. We have spoken of the end of the needle that points north as — or negative. Following this nomenclature, the northern magnetic pole of the earth must be + or positive. (See Report of the British Association Committee on Electrical Standards, Appendix C, 1863.) But popular usage calls the north-seeking end of the needle the north pole, and the other end the south pole. This introduces great confusion when we wish to speak of the magnetic poles of the earth. The nomenclature that we have adopted obviates this confusion.

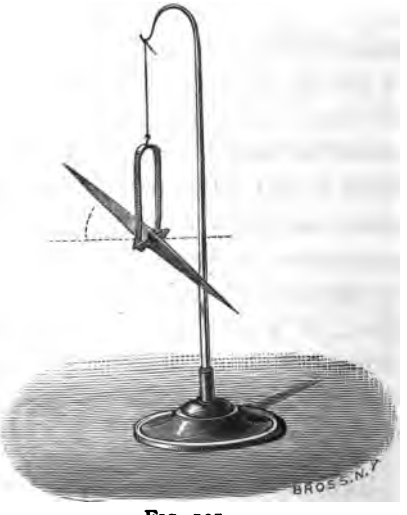


FIG. 131.

318. Inclination or Dip.—*The angle that a*

dipping needle makes with a horizontal line is called its inclination or dip. At the magnetic poles the inclination is 90°; at the magnetic equator there is no inclination. The inclination at any given place is not greatly different from the latitude of that place.

319. Declination or Variation.—The magnetic needle, at most places, does not lie in a north and south line. *The angle which the needle makes with the geographical meridian is its declination or variation.* A line drawn through all places where the needle points to the true north is called *a Line of no Variation.* Such a line, nearly straight, passes near Cape Hatteras, a little east of Cleveland, through Lake Erie and Lake Huron. It is now slowly moving westward. At all places east of the *Line of no Variation,* the — end of the needle points west of the true north; at all places west of the Line of no Variation, the variation is easterly. The further a place is from this line, the greater the declination—it being nearly 20° in Maine and more than 20° in Oregon.

320. Magnetization.—A common way of magnetizing a steel bar is to draw one end of a strong magnet from one end of the bar to the other, repeating the operation several times, *always in the same direction.* A second method is to bring together the opposite poles of two magnets at the middle of the bar to be magnetized, and simultaneously drawing them in opposite directions from the middle to the ends. A third method, represented in Fig. 132, is known as "the double touch." The opposite poles of two magnets are kept at a fixed distance from each other by means of a wooden block placed between them. The magnets thus held are moved from the middle toward one end of the bar, thence to the other end, repeating the operation several times, and finishing at the middle when each half of the bar has received the same number of frictions. But better than any of these can give are the effects produced by electro-magnetism. (§ 394.)

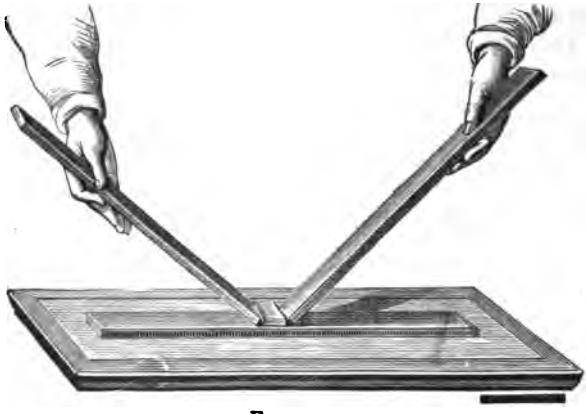


FIG. 132.

321. Armatures.—Magnets left to themselves would soon lose their magnetism by the recombination of their magnetic fluids. They must therefore be provided with armatures. *Armatures are pieces of soft iron placed in contact with opposite poles*, as shown in Fig. 133. The two poles of the magnet (or magnets, for two bar magnets may be thus protected) act inductively upon the armature and produce in it poles opposite in kind to those with which they come in contact. The poles of the armature in turn react upon the magnet, and, by their power of attraction, aid in preventing the recombination of the fluids in the magnet. The armature is sometimes the iron axle of a brass wheel; it is then called a rolling armature. Hold a horse-shoe magnet by its middle, slightly depress the poles, place the wheel upon the arms of the magnet as shown in Fig. 134, and allow it to roll to the end. Its momentum will carry the axle around the ends of the magnet, and the wheel will roll back to the middle, with the axle *on the under side of the magnet.*

FIG. 133.

FIG. 134.

Exercises and Questions.

1. (*a.*) What is a magnetic pole? (*b.*) A magnetic equator? (*c.*) How does a magnet behave toward soft iron? (*d.*) How does soft iron behave toward a magnet?

2. (*a.*) State carefully the various effects which one magnet may exert upon a second magnet. (*b.*) Generalize these observed facts into a law.

3. (*a.*) Give a theory of magnetism. (*b.*) State its merits and (*c.*) its demerits.

4. (*a.*) Given a bar magnet, how would you determine the sign of either of its poles? (*b.*) What is a diamagnetic substance?

5. (*a.*) Illustrate magnetic induction. (*b.*) Explain it. (*c.*) If a magnetic needle be freely suspended from its centre of gravity, what position will it assume?

6. (*a.*) Do you think that the earth is a magnet? (*b.*) Give a good reason for your answer. (*c.*) Do the magnetic and geographical meridians ever coincide? (*d.*) Do they always coincide? (*e.*) If they do not coincide, what name would you give to their difference in direction?

7. (*a.*) Does the magnetic attraction of the earth upon a ship's compass *tend* to float the ship northward? (*b.*) If so, why? If not, why not? (*c.*) What is an armature, and (*d.*) what is it good for?

8. (*a.*) State and illustrate the second law of motion. (*b.*) State and illustrate the law of universal gravitation. (*c.*) A body falls to the ground from rest in 11 seconds; what is the space passed over?

Recapitulation.—In this section we have considered Natural and Artificial Magnets; Magnetic Poles; the Attraction of a Magnet for Ordinary Iron; the Law of Magnets; a Broken Magnet; the theory of Magnetic Fluids and its value; Magnetic and Diamagnetic substances; magnetic Induction with illustrations; magnetic Curves; magnetic Needles; the Earth as a Magnet, and its inductive influence; the Nomenclature of magnetic poles; Dip and Variation; how to Make Magnets and how to Keep them.

SECTION II.

FRICTIONAL ELECTRICITY.

322. Preparatory.—Provide two stout sticks of sealing-wax and one or two pieces of flannel folded into pads about 20 *cm.* (8 inches) square; two stout glass tubes closed at one end, 30 or 40 *cm.* in length and about 2 *cm.* in diameter (long "ignition tubes") and one or two silk pads about 20 *cm.* square, the pads being three or four layers thick; a few pith balls about 1 *cm.* diameter (whittle them nearly round and finish by rolling them between the palms of the hands); a balanced straw about a foot long, represented in Fig. 135. The ends of the straw carry two small discs of paper (bright colors preferable) fastened on by sealing-wax. The cap at the middle of the straw is a short piece of straw fastened by sealing-wax. This is supported upon the point of a sewing-needle, the other end of which is stuck upright into the cork of a small glass vial. From the ceiling or other convenient support, suspend one of the pith balls by a fine silk thread. The efficiency of the silk pad above mentioned may be increased by smearing one side with lard and applying an amalgam made of one weight of tin, two of zinc, and six of mercury. The amalgam which may be scraped from bits of a broken looking-glass answers the purpose admirably.

FIG. 135.

323. Electric Attractions.—See that the sealing-wax and glass rods, the flannel and silk pads are perfectly dry. Have them quite warm, that they may not condense moisture from the atmosphere. For a moment briskly rub the sealing-wax with the flannel and bring the stick near the suspended pith ball. The ball will be drawn to the wax. Bring the wax near one end of the balanced straw; it may be made to follow the wax round and round. Bring it near small scraps of paper, shreds of cotton and silk, feathers and gold leaf, bran and sawdust, and other light bodies; notice that they are attracted to the wax.

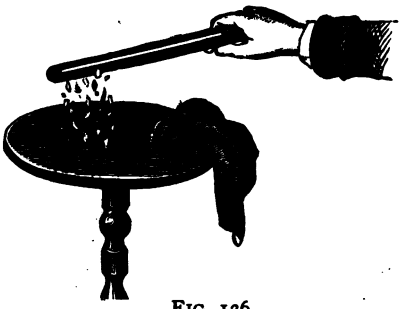


FIG. 136.

Repeat all of these experiments with a glass rod which has been rubbed with the silk pad (Fig. 136). You may make a light paper hoop or an empty egg-shell roll after your rod. Place an egg in a wineglass or egg cup. Upon its end balance a meter stick or a common lath. The end of the stick may be made to follow the rubbed rod round and round. Place the blackboard pointer or other stick in a stiff paper stirrup suspended by a stout silk thread or narrow silk ribbon. It may be made to imitate the actions of the balanced straw or lath. Now read § 64.

324. Electric Repulsion.—The suspended pith ball is called an electric pendulum. Bring the rubbed glass rod near the pith ball again. It will attract the ball as we have already seen in the last paragraph (Fig. 137). Allow the ball to touch the rod and notice that in a moment the ball is thrown off. If the ball be pursued with the rod, it will be found that the rod that a moment ago attracted now repels it (Fig. 138). Touch the ball with the finger; it successively seeks the rod, touches the rod, flies from the rod. Repeat the experiments with the sealing-wax after it has been rubbed with flannel. Rub the glass rod with silk and bring it over the small scraps of paper; notice that after the attraction the paper bits do not merely fall down, they are *thrown* down.

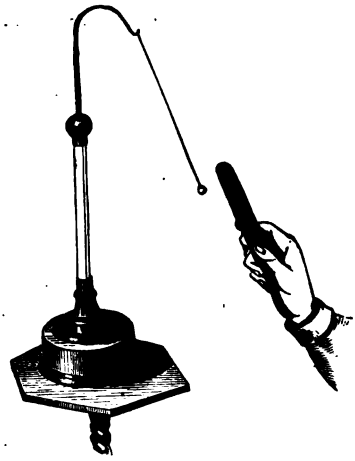


FIG. 137.

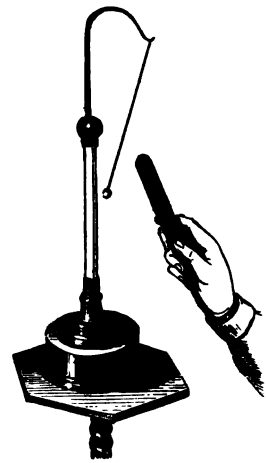


FIG. 138.

325. Electric Force.—We must by this time recognize the fact that we are dealing with a new class of phenomena. We have an agent here capable of producing motion; we have indisputable evidence of the presence of a force. This force is called electricity. *Electricity is a force manifested by the peculiar phenomena of attraction and repulsion.* It is believed that electricity is a form of molecular motion, but this belief rests upon analogy rather than demonstration.

326. Two Kinds of Electricity.—Prepare two electric pendulums. Bring the electrified glass rod near the pith ball of one; after contact, the ball will be repelled by the glass. Bring the electrified sealing-wax near the second pith ball; after contact it will be repelled by the wax. Satisfy yourself that the electrified glass will repel the first; that the electrified sealing-wax will repel the second. Let the glass rod and the sealing-wax change

hands. The first ball was repelled by the glass; it will be *attracted by the sealing-wax.* The second ball was repelled by the sealing-wax; it will be *attracted by the glass.* These experiments clearly show that *the electricity developed on glass is different in kind from that developed on sealing-wax.* They exhibit opposite forces to a third electrified body, each attracting what the other repels.

327. The Two Electricities Named.—As the two kinds of electricity are opposite in character, they have received names that indicate opposition. *The electricity developed on glass by rubbing it with silk is called positive or +; that developed on sealing-wax by rubbing it with flannel is called negative or —.* The terms *vitreous* and *resinous* respectively were formerly used.

328. Only Two Kinds of Electricity.—By repeating the experiments of § 326 with other substances, it is found that *all electrified bodies act like either the glass or the sealing-wax.*

329. The Law of Electric Action.—By the experiments already performed, we have made evident the fact that *two bodies charged with like electricities repel each other; two bodies charged with opposite electricities attract each other.*

330. The Test for Either Kind of Electricity.—When the pith ball was attracted by the rubbed glass it became, during the time of contact, charged with the + electricity of the glass; hence it was repelled. When it was attracted by the rubbed sealing-wax it became, during the time of contact, charged with the — electricity of the wax; then it was repelled. But either the wax or the glass attracted the uncharged pith ball. We must therefore

remember that *attraction affords no safe test for the kind of electricity, while repulsion does.* If glass rubbed with silk repels a body, that body is charged with + electricity. If sealing-wax rubbed with flannel repels a body, that body is charged with − electrfcity.

331. Electroscopes.—*An instrument used to detect the presence of electricity, or to determine its kind, is called an electroscope.* The electric pendulum (§ 324) is a common form of the electroscope. Two vertical strips of tissue paper, hanging side by side, constitute a simple electroscope. It is well to prepare the paper beforehand by soaking in a strong solution of salt in water and drying. The gold leaf electroscope is represented in Fig. 139. A metallic rod, which passes through the cork of a glass vessel, terminates below in two narrow strips of gold leaf and above in a metallic knob or plate. The object of the vessel is to protect the leaves from mechanical disturbance by air currents. The upper part of the glass is often coated with a solution of sealing-wax or shellac in alcohol, to lessen the deposition of aqueous vapor from the atmosphere. This instrument when well made is very delicate.

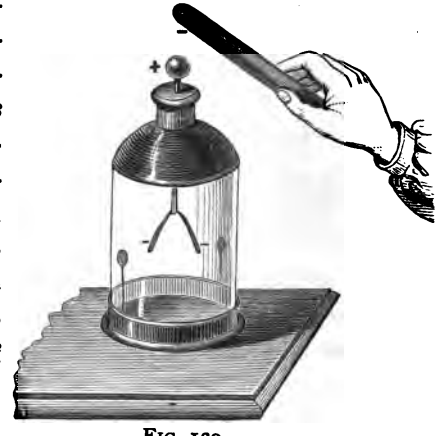


FIG. 139.

332. Use of the Electroscope.—(*a.*) The electric pendulum is used as an electroscope as follows: If the uncharged pith

ball is attracted by a body brought near it, the body is electrified. To determine the sign of the electricity of the body thus shown to be electrified, the pith ball is allowed to touch it and be repelled. If now the ball be repelled by a glass rod rubbed with silk (or by any other body known to be positively charged), the pith ball and the body in question manifest + electricity. If the pith ball, after repulsion by the body whose electricity is under examination, be repelled by sealing-wax rubbed with flannel (or by any other body known to be negatively charged), the pith ball and the body in question manifest − electricity.

(*b.*) One way of testing with the gold leaf electrometer is to touch the knob or plate with the electrified body. The knob, rod and leaves are thus charged with the same kind of electricity, and the leaves diverge. If the leaves be rendered more divergent by holding a positively electrified body near the knob, the original charge was +; if this effect be produced by a negatively charged body, the original charge was −. This method is objectionable for the reason that if the original charge be at all intense, it is likely to tear the gold leaves. A safer method is as follows: Cautiously bring the electrified body *near* the knob; the leaves will diverge. Touch the knob with the finger; the leaves will fall together. Remove first the finger and then the electrified body; the leaves will diverge again. If now the divergence of the leaves be increased by bringing a positively charged body near the knob, the original charge was −; if the divergence be thus diminished, the original charge was +. (See Appendix, K.)

333. Conductors.—From a horizontal glass rod or tightly-stretched silk cord, suspend a fine copper wire, a linen thread and two silk threads, each at least a meter long. To the lower end of each attach a metal weight of any kind. Place the weight supported by the wire upon the plate of the gold leaf electroscope. Bring the electrified glass rod near the upper end of the wire; the gold leaves *instantly* diverge. Repeat the experiment with the linen thread; *in a little while* the leaves diverge. Repeat the experiment with the dry silk thread; the leaves do not diverge *at all.* Rub the rod upon the upper end of the silk thread; no divergence *at all.* Wet the second silk

cord thoroughly, and with it repeat the experiment; the leaves diverge *instantly*. Balance a meter stick or common lath upon a wine-glass. About an inch below one end of the stick support a few bits of paper or gold leaf. To the other end of the lath bring an electrified glass rod. The bits of paper will be alternately attracted and repelled by the stick. Continue these experiments with other substances until you are convinced that *some substances transmit electricity readily and that others do not.* Those that offer little resistance to the passage of electricity are called *conductors;* those that offer great resistance are called *non-conductors* or *insulators*. A conductor supported by a non-conductor is said to be insulated.

334. Electrics.—*Any substance, when insulated, may be sensibly electrified; but when an uninsulated conductor is rubbed, the electricity escapes as fast as it is developed.* Thus we see that the old division of bodies into electrics and non-electrics, or bodies that may be electrified and those that cannot be electrified, is nothing more than a division into conductors and non-conductors.

(*a*.) Suspend a copper globe or other metal body by a silk thread and strike it two or three times with a cat's skin or fox's brush. Bring the gold-leaf electroscope near the globe. The leaves will diverge.

335. Theory of Electricity.—According to one provisional theory, electric action is due to two fluids, each self-repulsive; both mutually attractive (§§ 308, 309). When these opposite fluids (+ and −) are mixed in equal quantities, they neutralize each other and afford no manifestations. All bodies in the natural or unelectrified condition are pervaded by large quantities of this neutral fluid. By friction, chemical action and other means, this fluid may be decomposed, its two constituents being torn asunder. One fluid clings by preference to the rubber; the other to the body rubbed.

When a body is electrified, it gives up a part of one of the fluids and gains an equal amount of the other. The change is wholly in the kind; not at all in the quantity. The body which has an excess of + electricity is *positively* electrified. This involves an excess of − electricity in some other body which is *negatively* electrified at the same instant. Hence the electricity of the rubber must be of the kind opposite to that of the body rubbed. Experiment confirms the deduction.

336. Electric and Magnetic Fluids Compared.—These two sets of imaginary fluids have many obvious points of resemblance, but they have one marked difference. Neither magnetic fluid can leave the molecule to which it originally pertained; either one of the electric fluids may leave its molecule and be replaced by a like amount of its opposite.

337. Induction.—From several of the preceding experiments we see that actual contact with an electrified body is not necessary for the manifestation of electric action in an unelectrified body. When an electrified body *C*, is brought near an insulated unelectrified conductor *B*, the neutral fluid of the latter is decomposed by the influence of the former. The electricity of *C*, repels one constituent of the neutral fluid in *B* and attracts the other, thus separating them. The second body, *B*, is then said to be *polarized*. The same fluids of *B*, each of which a moment ago rendered the other powerless, are still there in full quantity, but they have been separated and each clothed with its proper power. This effect is due to the mere presence of the electrified body *C*, which is said to decompose the neutral fluid of *B* by *induction*. When *C* is removed, the separated fluids of *B* again mingle and neutralize each other.

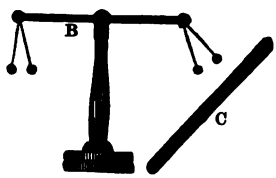


FIG. 140.

338. Analogous to Magnetic Induction.—We must master this subject even at the expense of repetition,

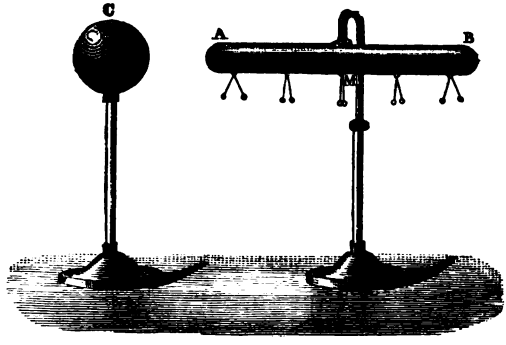


FIG. 141.

for induction is the only stepping-stone to an intelligent comprehension of what follows. If an insulated conductor, bearing a number of pith ball (or paper) electroscopes, be brought near an electrified body, *C*, but not near enough for a spark to pass between them, the pith balls near the ends of the conductor will diverge, showing the presence of uncombined electricity. The pith balls at the middle of the conductor will not diverge, marking thus a neutral line.

339. Charging a Body by Induction.—If the polarized conductor be touched with the hand, or otherwise placed in electric communication with the earth, the electricity repelled by *C* will escape, and the pith balls at *B* will fall together. The electricity at the other end will be held by the mutual attraction between it and its opposite kind at *C*. The line of communication with the ground being broken, and the conductor then removed from the vicinity of *C*, it will be found charged with elec-

tricity opposite in kind to that of *C*. Thus a body may be charged by induction with no loss to the inducing body.

340. Successive Induction.—If a series of insulated conductors be placed in line as shown in Fig. 142, and a positively electrified body be brought near, each conductor will be polarized. The first will be polarized by the influence of the + of *C*; the second by the influence of the + of *M*, and so on.

(*a*.) Either electricity from *M* or *N* may be carried by a small insulated body, called a proof-plane (Fig. 158), to the electroscope, there tested and found to be as represented in the figure. If the conductors *M* and *N* be now placed in actual contact, the + of both will be repelled by *C* to the furtherest extremity of *N* and the − of both attracted to the opposite end of *M*, near to *C*.

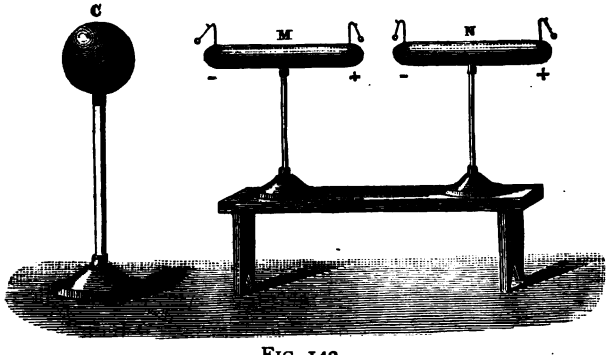


FIG. 142.

(*b*.) It is very plain that any body may be looked upon as a collection of many parallel series of such conductors, each molecule representing a conductor. Thus each molecule may be polarized, + on one side and − on the other. If the body in question be a good conductor of electricity, *this polarization of the molecules is only for an instant.* The two electricities pass from molecule to molecule and accumulate at opposite ends of the body. The body is then polarized, but not the molecules of the body. On the other hand, good insulators resist this tendency to transmit the electricities from molecule to molecule and are able to maintain a high degree of molecular polarization for a great length of time. In

brief, the molecules of conductors discharge their electricities easily into each other; those of non-conductors do not.

341. Polarization Precedes Attraction.—When an electrified glass rod is brought near an insulated uncharged pith ball (electric pendulum), the pith ball is polarized as shown in the figure. As the — of the ball is nearer the + of the glass than is the + of the ball, the attraction is greater than the repulsion. If the pith ball be suspended, not by a silk thread but by some good conductor, the attraction will be more marked, for the + of the ball will escape to the earth through the support, and the repelling component thus removed.

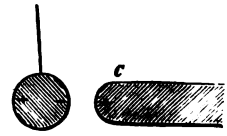


FIG. 143.

Note.—Polarization and electrification by induction explain a host of phenomena. Let the pupil apply this principle of *influence* or *induction* to pointing out the changes in the positions and conditions of the two fluids that are involved in the phenomena mentioned in § 323.

342. The Electrophorus.—This simple instrument consists generally of a shallow tinned pan filled with resin, on which rests a movable metallic cover with a glass or other insulating handle. The resinous plate may be replaced by a piece of vulcanized india-rubber. The metal surface and the resinous surface touch at only a few points; they are practically separated by a thin layer of air. (Appendix, K.)

FIG. 144.

(*a.*) The plate is rubbed or struck with flannel or catskin, and thus

negatively electrified. The cover is then placed upon the resin and thus polarized by induction. If the cover be provided with a gold-leaf electroscope, the free negative electricity of the cover will cause the leaves to diverge; the positive electricity of the cover will be "bound" on the under side of the cover by the attraction of the negative of the plate. Remove the plate, and the separated fluids reunite as is shown by the falling together of the lately divergent gold leaves. Place the cover again upon the plate. Polarization is manifested by the divergence of the leaves. Touch the plate with the finger as shown in the figure; the free — electricity escapes and the leaves fall. The cover is now charged positively, but its electricity is all "bound" at the under surface of the plate, and cannot cause the leaves to separate. Remove the plate by its insulating handle, and the electricity, lately "bound" but now "free," diffuses itself, and the leaves are divergent with + electricity. The charged cover will give a spark to the knuckle or other unelectrified body presented to it. (Fig. 145.)

343. The Electrophorus Charged by Induction.—The cover may be thus charged and discharged an indefinite number of times, in favorable weather, without a second electrifying of the resinous plate. This could not happen if the electricity of the cover were drawn from the plate. Moreover, if the charge of the cover were drawn from the plate, it would be —, and not +. There is no escape from the conclusion that the cover is charged by induction, and not by conduction.

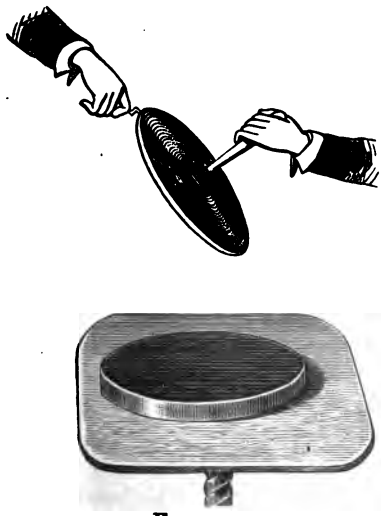


FIG. 145.

(*a.*) If the resin were a good conductor like the metal cover, its molecules would all receive + electricity from the cover and give — electricity to it. But as the resin is a poor conductor, only the very few molecules that come into actual contact with the cover at each charging have their electrical equilibrium restored. The + of the cover cannot pass through them to their electrified neighbors. Hence it requires a great many placings of the cover upon the plate to discharge the plate by reconveying to it the + electricity removed at its electrification. When the cover is charged, it gives up part of its — electricity; when it is discharged, it receives this — electricity back again from the body which discharges it. As this giving and taking is neither to nor from the resin, it may be continued indefinitely. A Leyden jar (§ 353) may be charged with an electrophorus.

344. Effect of Pointed Conductors.—Before proceeding to study the electrical machine we need to understand something of the action of pointed conductors. The reason of this action we shall see more clearly as we proceed; but the action itself, viz., that a strong charge of electricity will easily and quietly escape from a pointed conductor, is clearly shown by the following experiments: Place a carrot horizontally upon an insulating support. Into one end of the carrot stick a sewing-needle. Bring the electrified glass rod near the point of the needle without touching it. The — electricity of the carrot escapes from the point to the rod and the carrot is positively charged. And now for another experiment, not so easily made, but still certain to succeed if you are careful. Excite the glass rod, turn the needle away from it, and bring the rod near the other end of the carrot. The positive electricity is now repelled to the point from which it will stream into the air. Remove the rod and test the carrot; it is negatively electrified.

345. The Plate Electric Machine.—This instrument is represented in Fig. 146. It consists of an insulator (or electric), a

rubber, a negative and a prime conductor. The electric is a glass plate, one, two or three feet in diameter. This plate has an axis and handle, and is supported upon two upright columns. The rub-

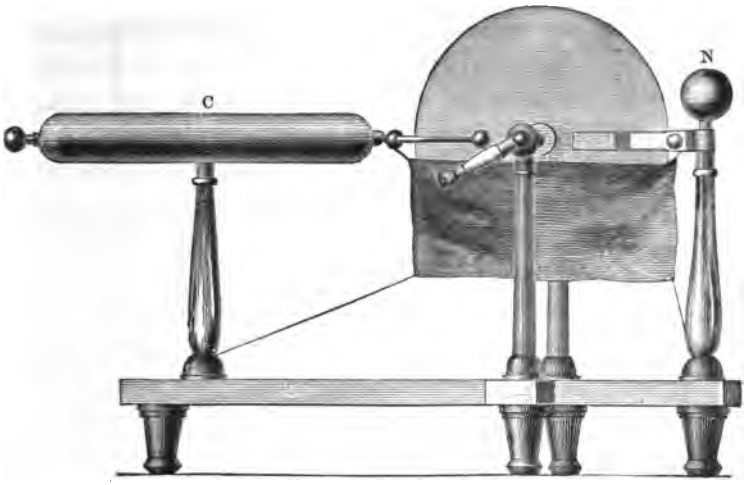


FIG. 146.

ber is made of two cushions of silk or leather, covered with amalgam. They press upon the sides of the plate and are supported from the negative conductor, with which they are in electric connection. The negative conductor, *N*, is supported upon an insulating column and placed in electrical connection with the earth by means of a chain or wire, not shown in the figure. The prime conductor, *C*, is supported upon an insulating column. One end of the prime conductor terminates in two arms, which extend one on either side of the plate. These arms being studded with points projecting toward the plate, are called *combs*. The teeth of the combs are not shown in the figure; they do not quite touch the plate. A silk bag is often supported so as to enclose the lower part of the plate. All parts of the instrument except the teeth of the combs are carefully rounded and polished, sharp points and edges being avoided.

346. Operation of the Plate Machine.—The plate is turned by the handle. The neutral fluid is decomposed by the friction of the rubbers. The + of the

rubber and negative conductor passes to the plate; the − of the plate passes to the rubber and negative conductor. The part of the plate thus positively charged passes to the combs of the prime conductor, being protected by the silk bag from discharge (neutralization) by the air on the way. The + of the plate acts inductively upon the prime conductor, polarizes it, repels the + and attracts the − electricities. Some of the − electricity thus attracted streams from the points of the combs against the glass, while some of the + of the glass escapes to the prime conductor. This neutralizes that part of the plate, or restores its electric equilibrium, and leaves the prime conductor positively charged. As each successive part of the plate passes the rubber it gives off − electricity and takes an equal amount of +; as it passes between the combs it gives off its + electricity and takes an equal amount of −. The rubber and negative conductor are kept in equilibrium by means of their connection with the earth, the *common reservoir*. As the plate revolves, the lower part, passing from *N* to *C*, is positively charged; the upper part, passing from *C* to *N*, is neutralized. If negative electricity be desired, the ground connection is changed from *N* to *C*, and the charge taken from *N*.

347. The Dielectric Machine.—This instrument is represented in Fig. 147. Two plates of vulcanite (ebonite), *A* and *B*, overlap each other without touching, and revolve in opposite directions. The upper plate is made to revolve much more rapidly than the lower by means of the pulleys shown at the right of the figure. The prime conductor and the axes of the two plates are carried by two insulating pillars. From the prime conductor a comb is presented to the upper part of the upper plate. Another comb is presented to that part of *A* which is overlapped by the upper part of *B*. This comb is connected by a universal joint at *e* with a discharging rod and ball, which may be brought near the end of the

prime conductor or turned away from it. The rubbers and the lower comb are to be in electrical communication with the earth. The general arrangement is clearly set forth in the figure.

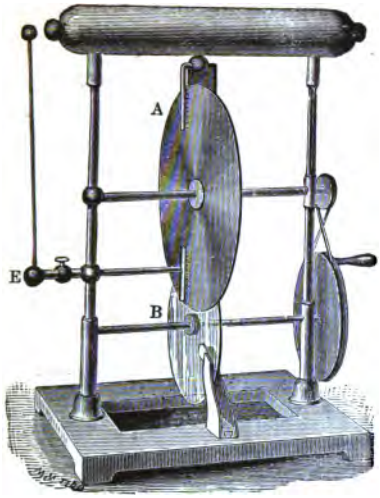


FIG. 147.

348. Operation of the Dielectric Machine.—The plate *B* is turned directly by the handle, and the plate *A* indirectly by the aid of the pulley. The plate *B* is negatively electrified by friction with the rubber, and thus acts by induction upon the lower part of *A*, which is thus polarized. The + of this part of *A* is bound by the attraction of the — of *B*, while the — of *A* is repelled, escapes by the lower comb, and is replaced by + from the earth through the lower comb and its ground connection. This part of *A*, thus positively charged, is soon removed from the inducing body, and the + charge *bound* by *B* is set free. It then comes to the upper comb, polarizes it and the prime conductor by induction, exchanges some of its own + for an equal amount of — from the prime conductor. This neutralizes that part of the upper plate, and leaves the prime conductor positively charged. As each successive part of *A* passes the lower comb it gives off — electricity and takes an equal amount of +; as it passes the upper comb it gives off + electricity and receives an equal amount of —. The charge of *B* is continually

maintained by friction with the rubber. When the discharging rod and ball are brought near the prime conductor, as shown in the figure, a rapid succession of sparks is produced, owing to the recombination of the separated electricities. If another body is to be charged from the prime conductor, the ball and rod may be turned aside. The power of this machine is greater than that of the plate or cylinder machine; it is less affected by atmospheric moisture, and is more compact.

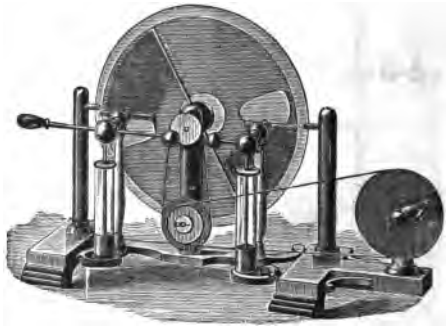


FIG. 148.

349. The Holtz Electric Machine.—This instrument is represented in Fig. 148. It contains two thin circular plates of glass, the larger of which is held fast by two fixed pillars. The smaller plate revolves rapidly very near it. There are two holes in the fixed plate near the extremities of its horizontal diameter. To the sides of these openings are fastened paper bands called armatures. Opposite these armatures, and separated from them by the revolving plate, are two metallic combs, connected respectively with the two knobs shown in the front of the picture. One of these knobs is carried by a sliding rod so that their distance apart is easily adjusted. In using the machine, the knobs are placed in contact, one of the armatures is electrified by holding against it an electrified sheet of vulcanite, the handle is turned for a few seconds, and the knobs gradually separated. A series of electric discharges between the two knobs takes place. When this machine works well, it gives results superior to either of those previously mentioned. It is, however, peculiarly subject to atmospheric conditions, and is generally considered extremely capricious.

Note.—When used, any electrical machine should be free from dust and perfectly dry. It should be warmer than the atmosphere

of the room, that it may not condense moisture from the surrounding air. The dryer the atmosphere the better will be the action of the machine.

350. Electric Density or Tension.—We already have the idea that all bodies, at all times and under all conditions, have a certain *quantity* of the electric fluid. This quantity may be all + or all —, or partly one and partly the other, the + and — mingling in all proportions. The kind may vary; the quantity is constant. If this quantity be equally divided between the + and the —, the body is unelectrified. If the + be slightly in excess, the body is feebly charged positively, and *vice versa*. If more — be replaced by more +, the positive charge is increased; that is, the *excess* of the positive over the negative is increased. This excess is the resultant or available force. If all of the — could be removed and an equal amount of + substituted therefor, the resultant would equal the total constant quantity and the charge would reach the theoretical maximum. What we call electric density or tension may be considered the value of this excess of either fluid over its opposite. When this excess or difference is great, the charge is said to be powerful or intense; the density or tension is great.

QUESTIONS.

1. (*a.*) Why is electricity called a force? (*b.*) How can you show that it is a force? (*c.*) Define *positive electricity*. (*d.*) Define *negative electricity*. (*e.*) How can you show that there are two opposite kinds of electricity?

2. (*a.*) How would you test the *kind* of electricity of an electrified body? (*b.*) Give the theory of two electric fluids.

3. (*a.*) What is a proof plane? (*b.*) An electroscope? (*c.*) Describe one kind of electroscope. (*d.*) Another kind.

4. (*a.*) Define *electrics, conductors* and *insulators*. (*b.*) Show the

relation of the first of these to each of the others. (*c.*) Explain electric induction.

5. (*a.*) If a metal globe suspended by a silk cord be brought near the prime conductor of an electric machine in action, feeble sparks will be produced. Explain. (*b.*) If the globe be held in the hand, stronger sparks will be produced. Explain.

Recapitulation.—In this section we have considered Electric Attraction and Repulsion; Electricity as a Force; the existence of Two Kinds of Electricity and their names; the Law of Electric Action; Tests for the presence and kind of Electricity; Electroscopes and their use; Conductors, Insulators and Electrics; the Theory of Electric Fluids; Electric Induction; Inductive Electrification; that Polarization Precedes Electric attraction; the Electrophorus; the Plate and the Dielectric machines and the Operation of each; the Holtz machine; Electric Tension.

SECTION III.

ELECTRIC CONDENSERS; LIGHTNING; EXPERIMENTS.

351. Condensation of Electricity.—By the words condensation of electricity we mean the process of increasing the charge which a body may receive from an electrified body having a given tension. If an insulated conductor be brought into contact with the charged prime conductor of an electric machine, the intensity of the charge received cannot exceed that of the prime con-

ductor, for obvious reasons. But if two conducting plates, A and B, separated by a non-conductor, C, be connected with the prime conductor, and the plate, A, provided with a ground connection, as shown in Fig. 149, the charge of B will be more intense than that of the prime conductor; its tension will be greater than that of the charging body. If a third plate like B, but having no opposite plate like A, be connected with B by a copper wire and the middle of the wire brought into contact with the prime conductor, nearly the whole charge will go to B and very little to the third plate, which has no condenser like A.

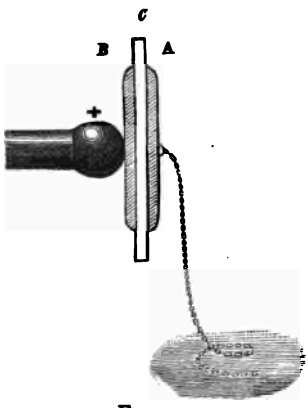


FIG. 149.

352. Electric Condensers.—The electric condenser is a contrivance by which the tension of the body charged may be made greater than the tension of the body charging. Let A and B, Fig. 150, represent two insulated metallic plates about six inches in diameter, separated by C, a plate of glass somewhat larger. Let each metallic plate have an electric pendulum, a and b. Remove A, and connect B with the conductor of the electric machine. The divergence of b shows the presence of free electricity. If the wire x were now cut, no change would take place. Connect A with the ground by the wire y, and place in position as represented. By the inductive influence of B, the neutral electricity of A is decomposed, its negative electricity being drawn to the surface n, while the positive escapes by y. But this negative electricity at n attracts the positive of B largely to the surface m, and holds it there as

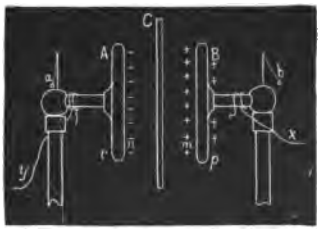


FIG. 150.

bound electricity. This change is shown by less divergence of *b*. Consequently *B* can receive more electricity from the machine, which will attract more negative electricity to *n*. This further supply will in turn bind more of the positive electricity of *B* at *m*. In this way a large quantity of positive electricity may be accumulated at *m*, and a large quantity of negative at *n*. This accumulation may thus go on until the intensity at the surface, *p*, is equal to that of the machine, as it was when *A* was absent. Interrupting communication by *x* and *y*, both plates are charged. The vertical pendulum *a* shows no *free* electricity, the electricity of *A* being all bound at *n*; the pendulum at *b* shows some free electricity, although the greater part of the electricity of *B* is bound at *m*. Remove *A* and *B* from each other, and the bound electricity of each is set free, and both *a* and *b* are widely divergent. The complete apparatus is represented by Fig. 151.

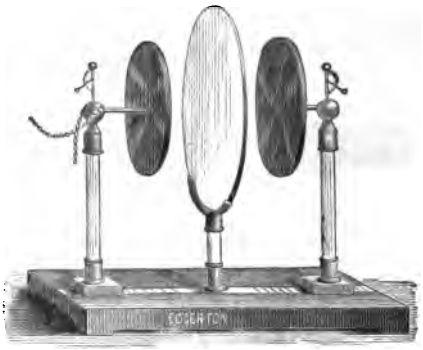


FIG. 151.

353. The Leyden Jar.—The Leyden jar consists of a glass jar coated within and without for about two-thirds its height with tinfoil. The mouth of the jar is closed with a cork through which passes a metallic rod, communicating by means of a small chain with the inner coat and terminating above in a knob. The cork and the upper part of the jar are generally coated with sealing-wax or shellac varnish to lessen the deposition of moisture from the air. It is evidently a modified electric condenser. The inner coat represents the collecting plate *B*; the glass jar, the insulator plate *C*; the outer coat the condensing plate *A* (Fig. 150).

FIG. 152.

354. Charging the Leyden Jar.—To charge the jar, hold it in the hand as shown in Fig. 153, and bring the knob near or into contact with the prime conductor of an electrical machine which is in action.

(*a.*) The prime conductor being positively charged attracts the − from the inner coat and replaces it with its own +. This + charge of the inner coat acting inductively through the glass polarizes the

FIG. 153.

outer coat, repelling the + which escapes through the hand to the earth, and binding its − to the surface in contact with the glass. This bound negative electricity of the outer coat, in turn, binds the positive of the inner coat, and so on. If, instead of holding the outer coat in the hand, the jar be supported upon a pane of glass so that the repelled electricity of the outer coat cannot escape, the jar cannot be very intensely charged.

355. Discharging the Leyden Jar.—The jar might be discharged by touching the knob with the finger, the separated electricities coming together through the person of the experimenter and the earth. In this case the experimenter will feel a "shock." If the charge be intense, the shock will be painful or even dangerous. It is better to use a "discharger," two forms of which are represented in Fig. 154. This consists of two metal arms hinged together, carrying knobs at

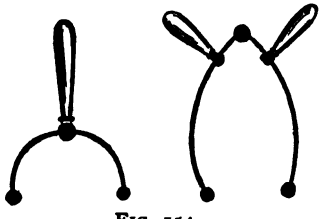


FIG. 154.

their free ends and carried by insulating handles. The outer coat should be touched first. Why?

356. The Leyden Jar with Movable Coats.—This piece of apparatus is represented by Fig. 155. The three parts being placed together in proper order, *B* within *A* and *C* within *B*, the jar is charged in the usual manner. The inner coat *C* is then removed with a glass rod and touched with the hand to discharge it fully. *B* is then lifted out from *A* and the outer coat fully discharged. The three parts are then put together again and found to be able to give nearly as strong a spark as at first. This seems to indicate that the charge rests upon the surfaces of the glass rather than upon the surfaces of the coats. If when the charged jar is in pieces, the thumb be placed on the outer surface of the glass and the forefinger of the same hand on the inner surface, a very slight shock is perceptible. The oppositely charged glass molecules that come into actual contact with thumb and finger respectively are discharged. By changing the position of the thumb and finger, successive little shocks may be felt as successive portions of the inner and outer surfaces of the glass are discharged. The inner coat furnishes a means for the simultaneous discharge of the inner layer of glass molecules; the outer coat does the same for the outer layer of glass molecules. Thus all or nearly all of the electrified glass molecules may be discharged simultaneously instead of successively.

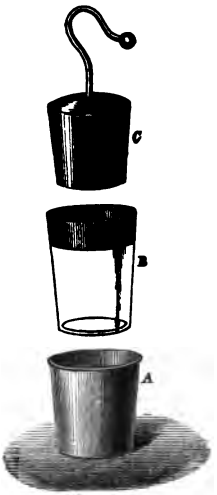


FIG. 155.

357. The Leyden Battery.—The effect that may be produced with a Leyden jar depends upon its size and the thinness of the glass. But a large jar is expensive and requires great care; thin glass is liable to perforation by the condensed and strongly attracting electricities of its two coats. To obviate both of these difficulties a collection of jars is used. When their outer coats are in electric communication, which may be secured by placing them in a

tray, the bottom of which is covered with tinfoil, and their inner coats are connected by wires or metal strips passing

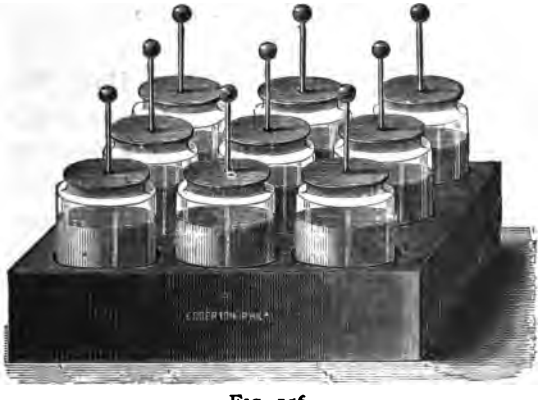


FIG. 156.

from rod to rod, or from knob to knob, the apparatus is called a Leyden or electric battery. The battery is

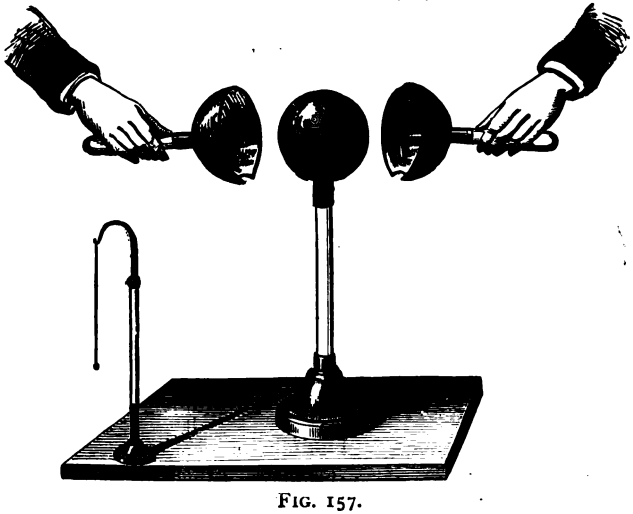


FIG. 157.

charged and discharged in the same way as a single jar; but great care is needed, for if the discharge were to take place through the human body the result would be serious and possibly fatal.

358. Distribution of Electricity.—Many experiments have been made which go to show that when a body is electrified, the electricity *passes to the surface* and escapes if the body be not insulated. A bomb-shell and a cannon-ball of equal size will receive equal quantities of electricity from the same source. The hollow conductors used in electric experiments are as serviceable as if they were solid.

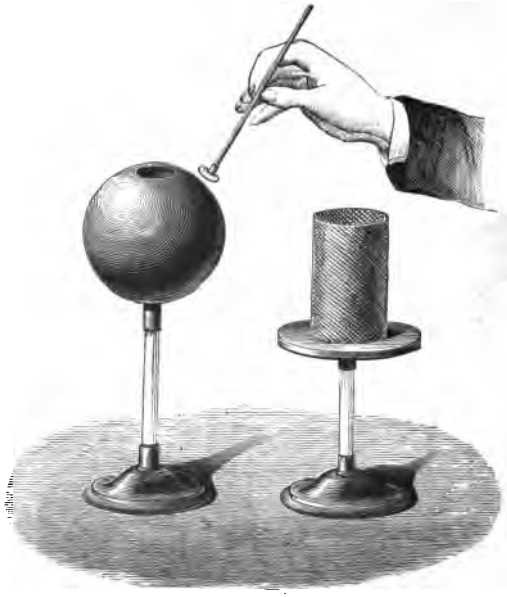


FIG. 158.

(*a.*) A metal globe with an insulating support (Fig. 157) is provided with two closely-fitting hemispherical shells having insulating

handles. Electrify the globe; bring it near the electroscope to be sure that it is electrified. Place the hemispheres upon the globe. Remove them quickly, being careful that their edges do not touch the sphere after the first separation. Bring first one shell and then the other near the electroscope; they are electrified. Bring the globe itself near the electroscope. *It is no longer electrified.* Delicate manipulation is needed to make the experiment successful. You will fail, perhaps, more times than you succeed. But when the experiment is successful, it is instructive. The apparatus is called Biot's hemispheres.

(*b.*) Charge with electricity a hollow sphere having an orifice in the top. Bring a proof-plane, made by fastening a disc of gilt paper to a long thin insulating handle, into contact with the outer surface of the sphere. The proof-plane is charged by the sphere, as may be shown by bringing it near an electroscope. Discharge the proof-plane and bring it into contact with the inner surface of the sphere. Remove it carefully without allowing it to touch the sides of the orifice. Bring it to the electroscope. It is not charged. (Fig. 158.)

(*c.*) Vary the experiment by the use of Faraday's bag. This consists of a conical bag of linen, supported, as shown in Fig. 159, by an insulated metal hoop five or six inches in diameter. A long silk thread extending each way from the apex of the cone enables the experimenter to turn the bag inside-out without discharging it. Whichever surface of the linen is external, no electricity can be found upon the inside of the bag. Nothing can be more conclusive than this.

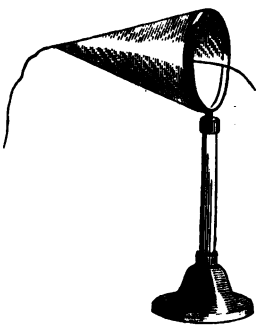


FIG. 159.

(*d.*) Vary the experiment by the use of a hat suspended by silk threads. Notice that the greatest charge can be obtained from the edges; less from the curved or flat surface; none from the inside.

Note.—This rule does not apply to an electric current. A hollow wire will not conduct electricity as well as a solid wire of the same diameter. Electricity may be *drawn* to the inside of a hollow conductor by placing there an insulated body oppositely charged.

359. Distribution of Electricity on the Surface.—Experiments show that when a sphere is charged, the electricity is evenly distributed over the sur-

face. Similar experiments on an elongated cylinder, like the prime conductor of the electric machine, show that the density is greater at the ends. On an ovoid conductor, like that shown in Fig. 160, the density is greatest at the smaller end. In general, the electric density is greatest on those parts of a charged conductor which project the most and have the sharpest ends. This tension at a point may become so great that the electricity will escape rapidly and quietly. This explains the action of points, which plays so important a part in the action of electric machines. This property will be illustrated in several of the experiments in § 371. It is also fundamental to the action of lightning-rods.

FIG. 160.

360. Atmospheric Electricity.—The identity of lightning with electricity, though long suspected, was first proved by Franklin's famous kite experiment. The atmosphere is, at all times, more or less electrified. The kind and intensity of this atmospheric electricity varies at different times. In fair weather, the atmospheric electricity is generally positive. The friction of moving masses of air probably contributes to the presence of atmospheric electricity.

361. Electrified Clouds.—Dry air being a poor electric conductor (§ 333), the air particles discharge their electricity into each other slowly and with difficulty. The electricity thus prevented from accumulating has little density or tension, and hence gives few manifestations of its presence. The moist particles which constitute a cloud being good conductors, the atmospheric electricity

involved in the cloud is quickly discharged from one particle to another, and accumulates on the surface of the cloud (§ 358). A cloud may thus become intensely charged. The charge is generally positive.

362. Lightning.—When a cloud positively charged floats over the earth, separated from it by a layer of insulating air, the inductive influence of the cloud renders the ground beneath negatively electrified. Then the cloud, ground, and insulating air, correspond respectively to the inner and outer coatings and the insulating glass of a Leyden jar. As the charge of a Leyden jar may be made so intense that the mutual attraction of the separated electricities will result in their rushing together and thus piercing the jar (§ 357), so the charge of a cloud may become sufficiently intense to overcome the intervening resistance and a lightning stroke ensues. Two clouds charged with opposite electricities may float near each other. Then they, with the intervening air, may be looked upon as constituting a huge Leyden jar. Thus we may see the lightning leaping from cloud to earth, or from cloud to cloud.

363. Lightning-Rods.—The value of lightning-rods depends upon the tendency of electricity to follow the best conductor, and upon the effect of pointed conductors upon electrical intensity (§ 359). The lightning-rod should, therefore, be made of a good conductor; copper is better than iron. It should terminate above in one or more points, tipped with some substance that may be corroded or fused only with extreme difficulty. Platinum is a metal which satisfies these conditions very well. The rod should extend above the highest point of the

building in order to offer the electricity the shortest path to the ground. It is important to have each projecting part of the building, as chimneys, towers and gables, protected by a separate rod. The rod should afford an unbroken connection; the joints, if there be any, should be carefully made. The rod should terminate below in water, or in earth that is *always* moist. A rod having a blunted tip, a broken joint, or terminating in dry earth, *is more dangerous than no rod at all.*

(*a.*) The greatest value of a lightning-rod is due to its quiet work in the *prevention* of the lightning stroke. Bring the point of a knife-blade near the conductor of an electric machine in operation, and notice the instant cessation of sparks. The quiet passage of electricity from the earth neutralizes the charge of the conductor and restores the electric equilibrium. In the same way, a lightning-rod tends to restore the electric equilibrium of the cloud, and prevent the dangerous discharge. For this quiet but very valuable service, few persons ever give the rod any credit. Every leaf of the forest and every blade of grass is a pointed conductor acting in the same way. (§ 371 [9].)

364. Velocity of Electricity and Duration of the Spark.—Experiment has shown that the velocity of electricity along an insulated copper wire is about 288,000 miles per second, and that the duration of the electric spark is not more than $\frac{1}{24000}$ of a second. The danger from any lightning stroke has passed when we hear the crash. (§ 425.)

365. Thermal Effects.—When an electric current has to overcome a resistance in its passage, heat is produced. By passing a strong current over a small wire, the wire may be heated to fusion. Metals have even been vaporized by electricity. The worse conductor a wire is, the more it is heated. See § 371, [19]–[23]. By means of a Leyden battery and a universal discharger, remark-

able thermal effects may be obtained. Houses are sometimes set on fire by lightning.

366. Luminous Effects.—The luminous effects of electricity are due to discharges through bad conductors. The electric spark is the most familiar example. The glow seen when electricity escapes from a pointed conductor in the dark, and the various forms of lightning, render familiar the luminous effects of electricity. (§ 371, [24]–[31]).

367. Magnetic Effects.—A common needle may be magnetized by winding about it a covered copper wire and discharging a Leyden jar through the wire. The magnetic effects of electricity are better and more commonly shown with Voltaic electricity. (§ 392.)

368. Chemical Effects.—The electric spark may be made to produce chemical combination or chemical decomposition. Ammonia gas (NH_3), or carbonic acid gas (CO_2), may be decomposed by passing a series of sparks through it. A mixture of oxygen and hydrogen may be caused to enter into chemical union by the electric spark, the product of the union being water (H_2O). (§ 371 [35].)

369. Mechanical Effects.—The piercing of the glass walls of an overcharged Leyden jar affords a good, though expensive, illustration of the mechanical effects of electricity. Trees and telegraph poles shattered by lightning are not unfamiliar. (§ 371 [32]–[34].)

(*a.*) Charge a Leyden jar. In discharging it, hold a stiff card between the knob of the jar and the knob of the discharger. A hole will be pierced through the card. By the side of this hole in the card make another with a pin. Any one can tell by examination of the pin-hole from which side of the card it was pierced; it is burred on only one side. Not so with the perforation made by

electricity; *it is burned on both sides.* The phenomena of attraction and repulsion, already made familiar, come under this head.

370. Physiological Effects. — The "electric shock," which is physiological in its nature, is familiar to most persons. The sensation thus produced cannot be described, forgotten or produced by any other agency. It has been found an efficient agent in medical practice. Such experiments, however, should be performed with caution.

(*a.*) If the members of a class form a chain by joining hands, the first member holding a feebly-charged Leyden jar by its outer coat, and the last member touching the knob, a simultaneous shock will be felt by each person in the chain. A single Leyden jar has thus been discharged through a regiment of 1500 men, each soldier receiving a shock. Dr. Priestley killed a rat with a battery of seven feet of coated surface, and a cat with a battery of forty feet of coated surface.

371. Apparatus and Experiments.—It is not necessary nor very desirable that all of the following experiments be performed. Several of them involve the same principle; but one teacher may have one piece of apparatus and another, another piece.

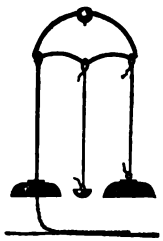


FIG. 161.

(1.) Fig. 161 represents the "electric bells." The metal frame is hung from the prime conductor. The right-hand bell is suspended by a wire; the other bell is suspended by a silk cord and connected with the ground by means of a chain hanging on the floor. When the machine is worked slowly, the clapper vibrates and rings the bells. *Explain.*

FIG. 162.

(2.) In the "electric chime," represented in Fig. 162, the outer bells

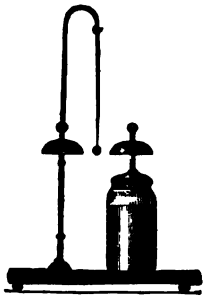


FIG. 163.

are to be put into communication with the prime conductor; the larger central bell is in communication with the earth. The clappers are suspended by silk threads. When the machine is slowly worked, the bells begin to ring. *Explain.*

(3.) In the "Leyden jar and bells," shown in Fig. 163, the left-hand bell is in communication with the outer coat of the jar; the clapper is suspended by a silk thread. When the jar is charged and placed in position as represented, the bells begin to ring and continue to do so for a considerable time. *Explain.*

(4.) The "metallic plates and dancing images" are represented in Fig. 164. The images are made of pith. The upper plate is in communication with the prime conductor; the lower one with the earth. When the machine is worked, the images dance in a very ludicrous manner. *Explain.* Pith balls may be substituted for the images, the resulting phenomena being known as "Volta's hail." The experiment may be simplified by electrifying the inner surface of a glass tumbler by rubbing it upon the knob of the prime conductor, and placing the tumbler over some pith balls on the table.

FIG. 164.

FIG. 165.

(5.) In the "electric swing," shown in Fig. 165, the boy is suspended by silk cords. One of the insulated knobs is in communication with the earth; the other with the prime conductor. When the machine is worked, the boy swings to and fro. *Explain.*

(6.) Electrify a glass rod. Toss a small sheet of gold leaf into the air. Bring the rod near the leaf. The leaf is drawn toward the rod and then thrown off. Chase the leaf with the rod without letting it touch the ground. *Explain.*

(7.) Fasten one end of a long, small copper wire to the prime conductor. Near the other end of the wire, tie a silk cord and hang it from the ceiling or other support so that the end of the vertical part of the wire shall be at a convenient height. To this end of the wire attach a tassel about four or five inches long made of many strips of light tissue paper. Work the machine and the leaves will

diverge. *Explain.* Extend toward it your clenched fist; the leaves seek the fist. *Explain.* Instead of your fist, hold a needle toward the tassel; it will be blown away. *Explain.* Hold the needle upright under the tassel. The strips will collapse. *Explain.*

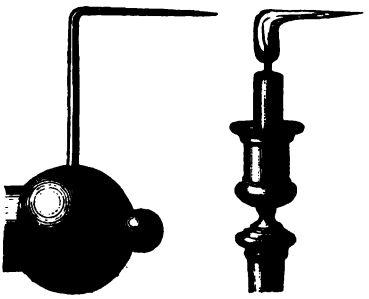


FIG. 166.

(8.) If the prime conductor be provided with a point, the flame of a candle held near will be blown away as shown in Fig. 166. If the candle be placed upon the prime conductor and a pointed conductor be held in the hand near the candle, the flame will be still blown away. *Explain.*

(9.) Stand upon the insulating stool and place your left hand upon the prime conductor of the electric machine. Hold in your right hand a sewing-needle with the tip of the forefinger covering the end of the needle. Bring the right hand cautiously near the gold-leaf electroscope. Notice the divergence of the leaves. Now uncover the point of the needle and bring it near the electroscope. Notice the marked and immediate increase in the divergence of the leaves. *Explain.*

(10.) Place an "electric whirl" (which consists of a set of horizontal wire arms radiating from a pivot-supported centre, the pointed ends being all bent in the same direction) upon the prime conductor. Work the machine and the arms will revolve. (See Fig. 167.) *Explain.*

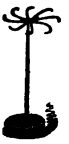


FIG. 167.

(11.) The "electric orrery," represented in Fig. 168, is a pretty modification of the "electric whirl." The short balanced bar is provided with a pointed conductor to produce rotary motion upon its supporting pivot, which is one end of the long balanced bar. This longer bar is also provided with a pointed conductor and supported in turn upon a pivot, which may be attached to the prime conductor. When the machine is worked, the long bar revolves upon its fixed pivot; the short bar revolves upon its moving pivot.

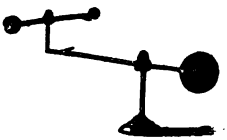


FIG. 168.

(12.) If a pupil, standing upon an insulating stool (a board supported by four warm tumblers will answer) and having one hand upon the prime conductor of an electric machine in action, bring a knuckle of the other hand near one end of the balanced meter stick (§ 323), it will follow the knuckle. *Explain.*

(13.) If, instead of placing one hand upon the prime conductor, he hold a Leyden jar by the outer coat and by a wire connect the knob of the jar with the prime conductor, his knuckle will attract the balanced meter stick when the machine is worked. *Explain.*

(14.) Half fill a wide glass vessel with water. Within this place a glass beaker and fill this to the same level with water. By a wire, connect the water in the outer vessel with the earth; in similar manner connect the water in the beaker with the electric machine. Give the handle of the machine a single turn. Dipping one finger into the outer water and another into the inner water, a shock is felt. *Explain.*

(15.) Coat both sides of a pane of glass with tinfoil to within three inches of the edge. Place the under coat in communication with the ground and the upper coat with the prime conductor. Place a coin upon the upper coat and work the machine. Try to remove the coin and a shock will be felt. *Explain.*

(16.) Let a pupil stand upon an insulating stool and place his left hand upon the prime conductor. Let him with his right hand clasp the left hand of another pupil not insulated, their hands being prevented from actual contact by an intervening sheet of india-rubber cloth. After the machine has been worked a moment, let the insulated pupil remove his left hand from the prime conductor and clasp the free hand of his companion. At this moment of clasping hands a shock will be felt. *Explain.*

(17.) Fasten a small paper kite by a linen thread to the prime conductor. When the machine is worked, the kite will float around the knob. *Explain.*

(18.) Place a few bits of paper upon the cover of the electrophorus. When the cover has been touched with the finger and lifted by the insulating handle, the paper will be thrown off. *Explain.*

(19.) Cover one knob of the discharger with gun cotton sprinkled with powdered rosin. When the Leyden jar is discharged with this discharger, the cotton and rosin are ignited.

(20.) The "electric bomb," represented in Fig. 169, may be made of ivory, heavy glass, or thoroughly-seasoned wood. The ends of the two metal wires are rounded and placed a short distance apart.

The bomb may be filled with gunpowder. One wire is connected by a chain with the outer coat of a charged Leyden jar. The other wire is to be connected with the inner coat by a *wet string* and the discharger. The spark between the ends of the two wires ignites the powder. Try the experiment with air instead of powder.

FIG. 169.

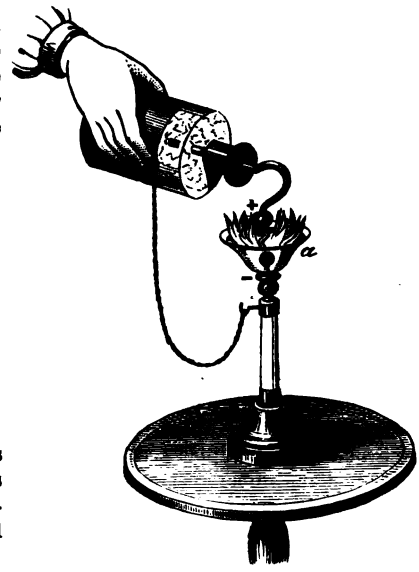


FIG. 170.

(21.) Fig. 170 illustrates a method of igniting an inflammable liquid, like ether or alcohol, by the electric spark. Through the bottom of a small glass vessel, *a*, passes a metal rod, having a knob at its upper extremity. The lower end of this rod may be brought into electrical connection with the outer coat of a Leyden jar. Enough ether or alcohol is poured into *a* just to cover the knob. When the jar is discharged in the way shown in the figure, the spark ignites the liquid. If alcohol is used it may have to be warmed to render the experiment successful.

(22.) Let a pupil, standing on an insulating stool, become charged by holding one hand on the prime conductor when the machine is in operation. If he then bring his knuckle to a metal burner from which a jet of gas is issuing, a spark will pass between the knuckle and the burner, igniting the gas. An Argand or Bunsen burner answers well for this experiment. The experiment may be modified by using, instead of the knuckle, an icicle held in the hand.

(23.) The "universal discharger," shown in Fig. 171, consists of a glass table and two insulated metal rods. The rods are provided

with balls, points and pincers. They are supported upon sliding and hinged joints, so that they may be easily placed in any desirable position. If the adjacent ends of the two rods be fitted with ball terminations placed upon the glass table, a small distance apart, a fine wire may be laid from one to the other. One of the rods may be connected by a wire or chain with the outer coats of a powerful battery; the other rod may be connected by the discharger (Fig. 154) with the inner coats of the battery. The current thus passed along the fine wire may heat it to incandescence, melt or even vaporize it.

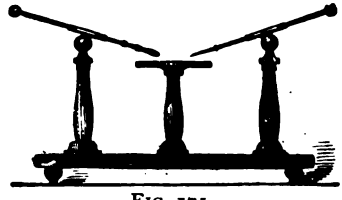


FIG. 171.

(24.) One of the inevitable experiments with an electric machine consists in "drawing sparks" from the conductor by the hand. When the tension of the separated electricities becomes sufficient to overcome the resistance of the intervening air, they recombine with a sharp explosive sound and brilliant flash of light. If the

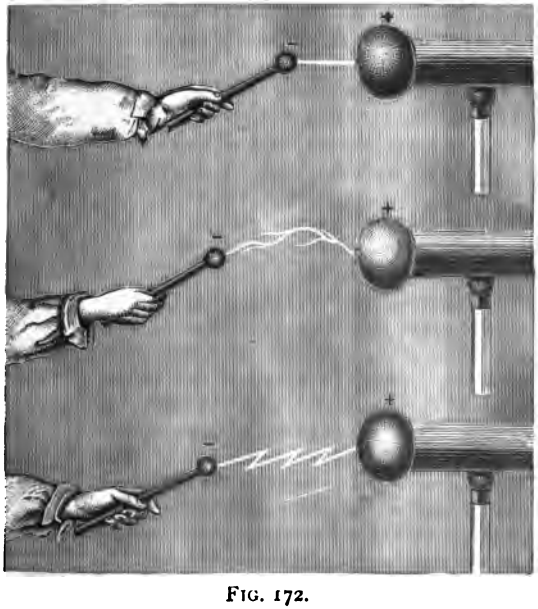


FIG. 172.

length of the spark be not great, the spark will be straight; if it be made somewhat greater, it takes a sinuous and forked form, as though floating dust particles served as stepping-stones and rendered a crooked path the easiest. If the charge be very powerful, the spark will take the zigzag form so familiar in the lightning-stroke. In the dark, the continuous discharge into the air produces a luminous appearance at the ends of the conductor. This appearance, known as a *brush*, may be improved by holding a large, smooth, metal globe at a distance a little too great for the passage of a spark. If the conductor be provided with a point, the point will *glow* when the machine is worked in the dark.

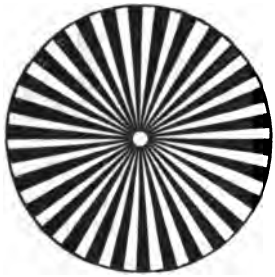


FIG. 173.

(25.) Divide a circle into black and white sectors, as shown in Fig. 173, and attach it to a whirling table (§ 74). Revolve it so rapidly that the colors blend and the disc appears a uniform gray. Darken the room and illuminate the rapidly revolving disc by the electric spark from a Leyden jar. The disc will appear at rest, and each sector will appear separate from its neighbors. This shows that the duration of the electric spark is less than the persistence of vision.

(26.) In a dark room, place a piece of loaf sugar in contact with the outside coat of a charged Leyden jar. Place one knob of the discharger upon the sugar, and bring the other near the knob of the jar. When the jar is discharged thus through the sugar, the sugar will glow for some time.

(27.) The "luminous jar," represented in Fig. 174, is a modified Leyden jar. The outer coat consists chiefly of a layer of varnish sprinkled over with metallic powder. A strip of tinfoil at the bottom affords means of communication with the earth. A similar band at the upper edge of the outer coat is provided with an arm, as shown in the figure. The rod of the jar is curved so as to bring the knob near the projecting arm of the outer coat. The jar is suspended by the curved rod from the prime conductor, and its lower strip of tinfoil connected with the earth. When the machine is worked, sparks pass between the knob and the projecting arm. In a dark room, the metallic powder

FIG. 174.

coat will be beautifully illuminated at the passage of each such spark.

(28.) The "luminous pane" is represented in Fig. 175. A continuous tinfoil strip is pasted back and forth upon the surface of a plate of glass. The upper end of this strip is connected with the prime conductor; the lower end with the earth. A series of breaks in this continuous conductor may be made by cutting it across with a sharp penknife. When the machine is worked a small spark will appear at each break thus made. These breaks may be arranged so as to represent a flower, star, arch, word or other design. The sparks are really successive, but they seem to be simultaneous. *Explain.*

FIG. 175.

FIG. 176.

(29.) The "luminous globe" is represented in Fig. 176, and the "luminous tube" in Fig. 177. The first of these consists of a hollow glass globe, on the inner surface of which small discs of tinfoil are placed very near each other. The first disc is in connection with the prime conductor, and the last one, with the ground. When the machine is worked, bright sparks appear at each break between the discs. The construction and action of the luminous tube are similar. Like the "luminous pane," these pieces of apparatus are intended for use in the dark. All of these lu-

FIG. 177.

FIG. 178.

minous effects are best exhibited in the dark.

(30.) If two barometer tubes, united at the top, be filled with mercury and inverted over two cups of mercury, as shown in Fig. 178, a Torricellian vacuum will be formed. When the mercury of one cup is connected with the prime conductor and the other with the earth, the upper part of the tube (containing only mercuric and other vapors) is filled with light. The luminosity may be increased by raising the temperature and thus increasing the density of the aëriform conductor. (A true vacuum will not conduct electricity.)

(31.) "Geissler's Tubes" for electric light are sealed glass tubes containing a highly rarefied vapor or gas, with which the tubes were filled before the exhaustion. Platinum wires are sealed into the glass at each end, to conduct the electric current. The brilliancy and beauty of the light, the great variety of effects, color, and fluorescence, are indescribable. They are made in great variety of form and size and filled with

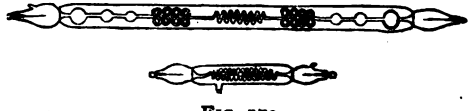


FIG. 179.

rarefied vapors and gases of many kinds. A few of the forms are represented in Fig. 179.

(32.) On the glass table of the universal discharger (Fig. 171) place a piece of wood and bring the *knobs* of the sliding rods against its ends so that the line joining the knobs shall be in the direction of the fibers of the wood. Through the apparatus thus arranged, discharge a powerful battery. The piece of wood will be torn in pieces.

(33.) Support a pane of glass upon a glass cylinder, in the axis of which is a pointed conductor which just touches the pane. On

the upper side of the pane directly over this pointed conductor place a drop of oil. From an insulated support lower a second pointed

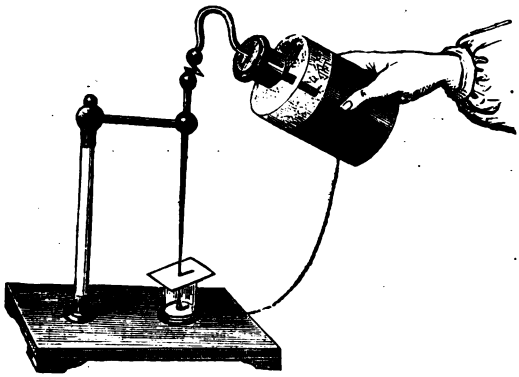


FIG. 180.

conductor until it touches the pane at the oil. Through these two pointed conductors (Fig. 180) discharge a Leyden jar *or battery*. Unless the glass is *very thin*, a single jar will not be sufficient. If the experiment fails the first time, do not use the same piece of glass for the second trial.

(34.) With corks, plug the ends of a glass tube filled with water. Through the corks, introduce copper wires until the ends in the water are within a quarter of an inch of each other. Through these wires discharge a Leyden jar. The mechanical shock due to the repulsion of the electrified water molecules will break the tube.

(35.) Fig. 181 represents "Volta's Pistol," which consists of a metal vessel through one side of which passes an insulated metal rod with knobs at both ends. The knob at the inner end of this rod is near the opposite wall, so that a spark may easily be made to pass between the knob and the body of the pistol. The pistol being filled with a mixture of illuminating gas and common air in equal volumes or with oxygen and hydrogen in the proportion of one volume of the former to two of the latter, and the mouth being closed by a cork, the passage of the spark brings about a chemical union of the mixed gases, a violent explosion ensues, and the cork is thrown some distance. The

FIG. 181.

spark may be produced by holding the pistol in the hand and bringing the outer knob near the prime conductor; or the pistol may be suspended from the prime conductor by a wire or chain and the pistol then touched with the hand. The pistol may be fired by means of the electrophorus (§ 342) or Cottrell's Rubber.

372. Relation of Electricity to Energy.—The work necessarily performed in operating an electric machine is not all expended in overcoming inertia and friction. Much of it is employed in producing electric separation. It matters not whether this separation be the separation of two fluids or of *something* else. Whatever be the nature of the realities separated, mechanical kinetic energy is employed in the separation and converted into the potential variety (§ 159). In every case of electric attraction or repulsion we have an evident reconversion of this potential into mechanical kinetic energy. We shall soon see that the sound, heat and light accompanying electric discharges are forms of energy due to the conversion of the potential energy of electric separation.

Exercises.

1. (*a.*) If a gold-leaf electroscope be placed within a tin pail which is insulated and electrified, what will be the action of the electroscope? (*b.*) Explain.

2. (*a.*) Why may one obtain a stronger spark from a Leyden jar than from the machine by which it is charged? (*b.*) A Leyden jar standing upon a glass plate cannot be strongly charged. Why?

3. (*a.*) A globe that is polished will remain electrified longer than one that is not polished. Why? (*b.*) Can you devise an appendage to the outer coat of a Leyden jar, so that it may be charged when standing upon a plate of glass?

4. (*a.*) Can you see any connection between electric induction and the fact that electricity dwells only upon the outer surface of a conductor? (*b.*) Describe the plate electric machine. (*c.*) Explain its action. (*d.*) Explain the action of the electrophorus.

5. (*a.*) A minute after the discharge of a Leyden jar, a second and feebler spark may generally be obtained. Explain (§ 356.) (*b.*) State two uses of lightning-rods.

6. (*a.*) Having a metal globe positively electrified, how could you with it negatively electrify a dozen globes of equal size without affecting the charge of the first? (*b.*) How could you charge positively one of the dozen without affecting the charge of the first?

7. Can you devise a plan by which a series of Leyden jars, placed upon a glass plate, may be simultaneously charged, the first positively, the second negatively, the third positively, the next negatively, and so on?

Recapitulation.—In this section we have considered the Condensation of electricity; the Leyden Jar; the Leyden Battery; the Distribution of electricity on conductors; Atmospheric Electricity; electrified Clouds and Lightning; Lightning Rods and their action; the Velocity of the electric current and the Duration of the electric spark; six Classes of Effects of electricity and many electric experiments.

SECTION IV.

VOLTAIC ELECTRICITY.—DYNAMO-ELECTRICITY AND THERMO-ELECTRICITY.

373. Chemical Action.—All chemical changes produce electric separation. This is true whether the substances subjected to chemical action be solid, liquid or aëriform; but the chemical action between liquids and metals gives results the most satisfactory. Electricity thus developed is called Voltaic or Galvanic electricity.

374. The Electric Current.—When a strip of copper and one of zinc are placed in dilute sulphuric acid, the two strips being connected above the acid by a wire conductor, a current of electricity is produced. In fact, two currents, opposite in kind and direction, are simultaneously produced, but to avoid confusion the negative current is ignored. *When reference is made to the direction of the current, it means the direction of the positive current.* The apparatus here described is called a Voltaic or Galvanic element.

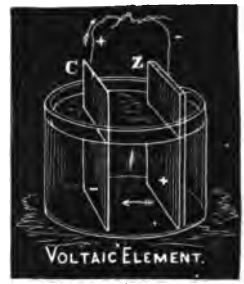


FIG. 182.

375. Direction of the Current.—For this production of the electric current, it is necessary that the liquid have a greater action upon one metal than upon the other. The metal most vigorously acted upon constitutes the generating or *positive* plate; the other, the collecting or *negative* plate. This relation of the plates determines the direction of the current. *In the liquid, the current is from the positive to the negative plate; in the wire, it is from the negative to the positive.*

376. The Electric Circuit.—When the wires from the two plates are in contact, it is said that the *circuit is closed;* when the plates are not thus in electric connection it is said that the *circuit is broken.*

(*a.*) When the circuit is closed, hydrogen is set free by the decomposition of the liquid and rises from the surface of the negative plate. The tendency of the hydrogen to adhere to the plate is one

of the practical difficulties to be overcome in working a Voltaic element or battery.

377. Electrodes.—It will be readily understood by keeping in mind the direction of the two currents, that, if the circuit be broken, negative electricity will accumulate at the end of the wire attached to the positive plate, and positive electricity at the end of the wire attached to the negative plate. *These ends of the wires are then called poles or electrodes. The negative pole is attached to the positive plate and vice versa.* For many experimental purposes, strips of platinum are fastened to the ends of the wires; these platinum strips then constitute the electrodes.

378. Resistance.—Even a good conductor (§ 333) offers a sensible resistance to the passage of an electric current; the poorer the conductor, the more resistance it offers to the passage of the current. Experiments show that the quantity of electricity passing in a unit of time, over a given conductor, is directly proportional to the electromotive force. (This electromotive force, "*E. M. F.*," is the supposed force that causes or tends to cause a transfer of electricity from one point to another.) When the *E. M. F.*, the sectional area and the material are constant, the resistance is proportional to the length of the conducting wire; doubling the length doubles the resistance and halves the current. When the *E. M. F.*, the length and material are constant, the resistance is inversely proportional to the area of the cross-section of the wire; halving that area doubles the resistance and halves the current. Since the resistance is inversely proportional to the area of the cross-section, it will also be proportional to the weight of the wire per unit of length. The difference between the resistance of a good conductor and that of an insulator is very great. The resistance of a silver wire being taken as unity, the resistance of a similar wire of German silver would be 12.82, while that of a similar rod of gutta-percha would be 8.5×10^{20}. Hence, insulators are often spoken of as bodies of great resistance.

379. A Voltaic Battery.—*A number of Voltaic elements connected in such a manner that the*

current has the same direction in all, constitutes a Voltaic battery. The usual method is to connect the positive plate of one element with the negative plate of the next, as shown in Fig. 183. When thus connected, they are said to be coupled "in series." Sometimes all of the positive plates are connected by a wire, and all of the negative plates by another wire. The cells are then said to be joined "in multiple arc." (See Fig. 184.)

380. Batteries of High and of Low Resistance.—Each kind of Galvanic cell has an internal

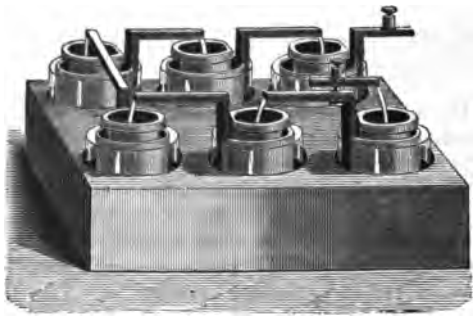


FIG. 183.

resistance, depending upon the liquid used, the distance between the plates, and the size of the plates. The resistance of the liquid conductor is several million times as great as that of a similar metal conductor. The distance between the plates determines the length of the liquid conductor (§ 378), and the size of the plates, its area of cross-section. A battery of cells joined in series is called a "battery of high resistance." A battery of cells joined in multiple arc is called a "battery of low resistance." For a long circuit of great external resistance, a battery of high resistance is needed. For a short circuit of small external

resistance, large cells, or several cells in multiple arc are preferable.

(*a.*) A battery of high resistance was formerly called an *intensity* battery, while a battery of low resistance was called a *quantity* battery.

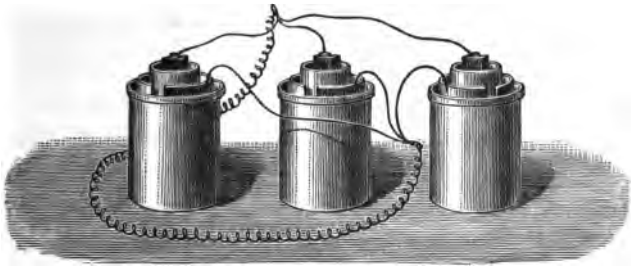


FIG. 184.

381. Daniell's Battery.—In the cell of Daniell's battery (Fig. 185), the zinc plate is in the form of a cleft, hollow cylinder. Within this cylinder is a porous cup; within the porous cup is the copper cylindrical plate. The liquid used is dilute sulphuric acid, but the acid within the porous cup has as much copper sulphate as it can dissolve, *i. e.*, it is saturated. For the purpose of keeping this acid saturated, crystals of copper sulphate are suspended in it near the surface, by means of a copper wire basket or perforated earthenware cup. The effect of this is to cause the hydrogen to re-enter into chemical combination before it reaches the copper plate. Copper, instead of hydrogen, is

FIG. 185.

deposited upon the copper plate. The current from this battery is especially constant.

(*a*.) In the figure, the copper plate is represented as a cleft cylinder within the porous cup, the crystals being piled up around it. It is common to interchange the plates, the zinc being in dilute sulphuric acid within the porous cup, and the copper plate in the saturated acid outside the porous cup. Sometimes the outer vessel itself is made of copper instead of glass, the vessel then becoming the negative plate. The internal resistance of a Daniell's cell is as great as that of a quarter of a mile of ordinary telegraph wire.

382. Smee's Battery.—An element of Smee's battery is represented by Fig. 186. It consists of a silver plate coated with platinum powder placed between two zinc plates, the plates being hung in dilute sulphuric acid. The use of the platinum powder is to free the plate from the liberated hydrogen.

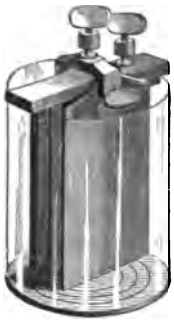


FIG. 186.

383. Potassium Bi-chromate Battery.—The potassium bi-chromate battery differs from Smee's in the substitution of a carbon plate for the silver plate, and of a solution of potassium bi-chromate in dilute sulphuric acid for the liquid there used. Here the hydrogen is given an opportunity for chemical union as fast as it is liberated.

(*a*.) The bottle form of this battery, represented in Fig. 187, is the most convenient for the laboratory or lecture table. By means of the sliding rod, the zinc plate can be raised out of the solution when not in use; and thus adjusted, the cell can remain for months without any action, if desired, and be ready at a moment's notice. One of the best propor-

FIG. 187.

tions for the solution is as follows: One gallon of water, one pound of bi-chromate of potash, and from a half-pint to a pint of sulphuric acid, according to the energy of action desired. A small quantity of nitric acid added to the solution increases the constancy of the battery.

(*b*.) The following recipe is good: Pour 167 *cu. cm.* of sulphuric acid into 500 *cu. cm.* of water, and let the mixture cool. Dissolve 115 *g.* of potassium bi-chromate in 335 *cu. cm.* of boiling water, and pour while hot into the dilute acid. When cool it is ready for use.

384. Grove's Battery. — The outer vessel of an element of Grove's battery contains dilute sulphuric acid. In this is placed a hollow cylinder of zinc. Within the zinc cylinder is placed a porous cup containing strong nitric acid. The negative plate is a strip of platinum placed in the nitric acid. The hydrogen passes through the porous cup and reduces the nitric acid to nitrogen peroxide, which escapes as brownish red fumes. A Grove's element is represented in Fig. 188.

FIG. 188.

385. Bunsen's Battery.—Bunsen's battery differs from Grove's in the use of carbon instead of platinum for the negative plate. The elements are made larger than for Grove's battery. It gives greater quantity and less intensity than Grove's (§ 380 [*a*]). A Bunsen's element is represented in Fig. 189.

FIG. 189.

Note.—There are scores of different batteries in the market competing for favor. With the exception of Smee's, those here described are the ones most commonly used.

386. Amalgamating the Zinc.—Ordinary commercial zinc is far from being pure. Chemically pure zinc is expensive. When impure zinc is used, small closed circuits are formed between the particles of foreign matter and the particles of zinc. This *local action* rapidly destroys the zinc plate and contributes nothing to the general current. This waste, which would not occur if perfectly pure zinc were used, is prevented by frequently amalgamating the zinc. This is done by cleaning the plate in dilute acid and then rubbing it with mercury.

(*a.*) The method of amalgamating battery zincs practised by the author is as follows: In a glass vessel placed in hot water, dissolve 15 *cu. cm.* of mercury in a mixture of 170 *cu. cm.* of strong nitric acid and 625 *cu. cm.* of chlorhydric (muriatic) acid. When the mercury is dissolved, add 830 *cu. cm.* of chlorhydric acid. When the liquid has cooled, immerse the battery zinc in it for a few minutes, remove and rinse thoroughly with water. The liquid may be used over and over until the mercury is exhausted. The quantity here mentioned will suffice for 200 ordinary zincs or more. Keep the liquid, when not in use, in a glass-stoppered bottle.

387. Thermal Effects of Voltaic Electricity.—When a strong current is passed over a very thin wire made of a poor conductor, as platinum or even iron, *the resistance develops heat which may render the wire incandescent or even fuse or vaporize it.* Thus the Voltaic current is often used in firing mines in military operations and blasting. (See § 389.)

(*a.*) If stout copper wires from the two plates of a potassium bi-chromate battery (Fig. 187) have their free ends united by a *very fine* iron wire, the passage of the current will heat it sufficiently to ignite gun cotton. All known metals, even iridium and platinum, have been melted in similar manner, while carbon rods have been heated by a battery of 600 Bunsen's elements until they softened enough for welding.

388. Luminous Effects.—When the circuit of a battery is closed or broken there is a spark at the point of contact. Beautiful luminous effects may be produced by winding the wire from one plate about the end of a file, and drawing the other electrode along the side of the file, thus rapidly closing and breaking the circuit.

389. The Voltaic Arc.—The most brilliant luminous effect of current electricity is the Voltaic arc or electric lamp. The electric lamp consists essentially of two pointed bars of gas carbon placed end to end in the circuit of a very powerful battery. If the ends of the carbons be separated a short distance while the current is passing, the carbon points become incandescent and the current will not be interrupted. *When the carbons are thus separated, the space between is filled with a luminous arch, the brilliancy of which exceeds that of any*

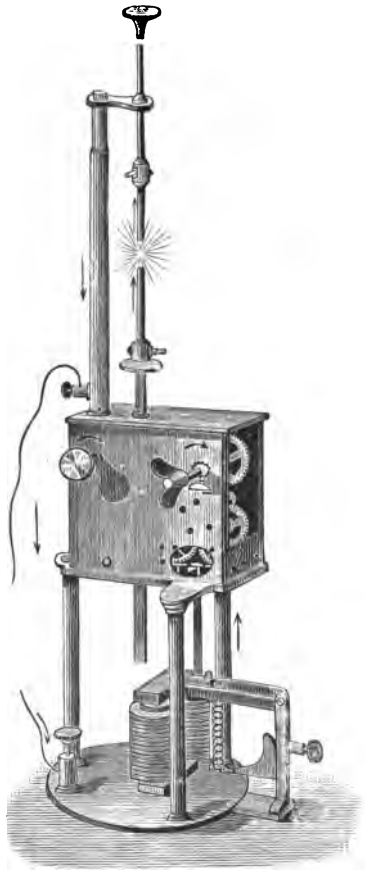


FIG. 190.

other light under human control, the temperature of which is unequalled by any other artificial source of heat.

390. Deflection of the Magnetic Needle.—The Voltaic current has a marked effect in the deflection of the magnetic needle, and tends to place the needle at right angles to the direction of the current. This may be easily shown by Oersted's apparatus represented in Fig. 191. It consists of a magnetic needle and a brass wire frame with three pole-cups, permitting the current to be passed over, under, or around the magnet.

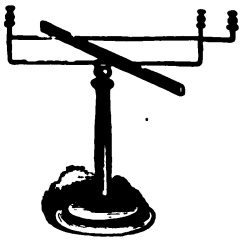


FIG. 191.

(*a.*) If the current pass *above* the needle from north to south, the — end of the magnet (§ 317) will be deflected toward the east; if it pass from south to north, the — end of the needle will be deflected toward the west. If the current pass *below* the needle, the deflections will be the opposite of those just mentioned.

391. The Galvanometer.—The galvanometer depends upon the principles set forth in the last article. *It is a very delicate piece of apparatus for detecting the presence of an electric current and determining its direction and intensity.* In Oersted's apparatus the needle is heavy, and a considerable force is needed to set it in motion; in the galvanometer the needle is very light, and is easily set in motion. In Oersted's apparatus the needle is held in the magnetic meridian by the directive influence

FIG. 192.

of the earth; in the galvanometer this is obviated almost wholly by the use of an astatic needle. In Oersted's apparatus, the current makes but a single course about the needle; in the galvanometer, the covered wire is coiled many times about the needle and thus the effect is multiplied. One of the needles is within the coil while the other swings above it, the two being connected by a vertical axis passing through an appropriate slit in the coil. If both needles were within the coil, since their poles are reversed (§ 314), the same current would tend to deflect them in opposite directions and thus the action of one needle would neutralize that of the other. The astatic needle is suspended by an untwisted silk fibre from a hook which may be lowered when the instrument is not in use until the upper needle rests upon the dial plate beneath it. The ends of the coiled wire are connected with binding screws; levelling screws are provided, by means of which the instrument may be adjusted so that the needles shall swing clear of all obstructions. A glass cover protects from dust and disturbance by air currents. The instrument is represented in Fig. 192.

392. Magnetic Effects of the Voltaic Current.—A bar of soft iron may be easily magnetized by the inductive influence of the Voltaic current. This is shown by the action of the bar and helix (Fig. 193).

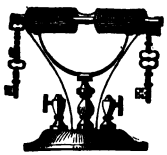


FIG. 193.

(*a*.) This apparatus consists of a movable bar of soft iron surrounded by a coil of insulated copper wire. When the wire of the coil is placed in the closed circuit of a battery, the iron bar becomes strongly magnetized; when the circuit is broken, the bar instantly loses its magnetic power. The same thing is illustrated by the "helix and ring

armature" shown in Fig. 194. The armature is of soft iron divided into two semicircles with brass handles. When the helix is placed in a closed circuit, the semicircles resist a considerable force tending to draw them apart; when the circuit is broken they fall asunder of their own weight.

FIG. 194.

393. Electro-Magnets.—The bar of Fig. 193, and the ring of Fig. 194, are electro-magnets. The electro-magnet more often has the horse-shoe form shown in Fig. 195. The middle of the bent bar is bare, the direction of the windings on the ends being such that, were the bar straightened, the current would move in the same direction round every part. Electro-magnets have been made capable of supporting several tons.

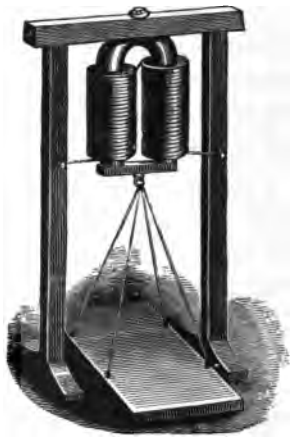


FIG. 195.

(*a.*) When the circuit is broken and the current thus interrupted, the iron is generally not *wholly* demagnetized. The small magnetism remaining is called *residual magnetism*. The residual magnetism seems to vary with the degree of impurity of the iron.

394. Making Permanent Magnets.—A steel bar may be permanently magnetized (§ 320) by drawing it, from its centre, in one direction over one pole of a powerful electro-magnet, and then, from its centre, in the opposite direction over the other pole, and repeating the process a few times. A bar of steel placed within a helix through which a strong current is passing, will be permanently magnetized. The arrangement is substantially like that shown in Fig. 193.

395. The Electric Telegraph.—The electric telegraph consists essentially of an electro-magnet and a "key" placed in the circuit of a battery. The key is an instrument by which the circuit may be easily broken or closed at will. The armature of the magnet is supported by a spring, which lifts it when the circuit is broken. When the circuit is closed, the armature is drawn down. Thus the armature may be made to vibrate up and down at the will of the person at the key. The armature may act upon one arm of a lever, the other end of which, being provided with a style or pencil, may be pressed against a strip of paper drawn along by clock-work. Thus the pencil may be made to record, upon the moving paper, a series of dots and lines at the pleasure of the operator at the key perhaps hundreds of miles away. When the two stations are several miles apart, one of the wires is dispensed with, the circuit being completed by the earth.

396. Morse's Alphabet.—The inventor of the electric telegraph was an American, S. F. B. Morse. The system of signals devised by him is given below:

	LETTERS.		FIGURES.
a · —	*j* · — — —	*s* · · ·	1 · — — — —
b — · · ·	*k* — · —	*t* —	2 · · — — —
c — · — ·	*l* — · — ·	*u* · · —	3 · · · — —
d — · ·	*m* — —	*v* · · · —	4 · · · · —
e ·	*n* — ·	*w* · — —	5 · · · · ·
f · · — ·	*o* — —	*x* — · · —	6 — · · · ·
g — — ·	*p* · — — — ·	*y* — · — —	7 — — · · ·
h · · · ·	*q* — — · —	*z* — — · ·	8 — — — · ·
i · ·	*r* · — ·	*&* · — · — ·	9 — — — — ·
			0 — — — — —

To prevent confusion, a small space is left between successive letters, a longer one between words, and a still longer one between sentences. Telegraph operators soon become so familiar with this

alphabet that they understand a message from the mere clicks of the lever, and do not use any recording apparatus.

397. Chemical Effects of the Voltaic Current.—Many chemical compounds in solution may be

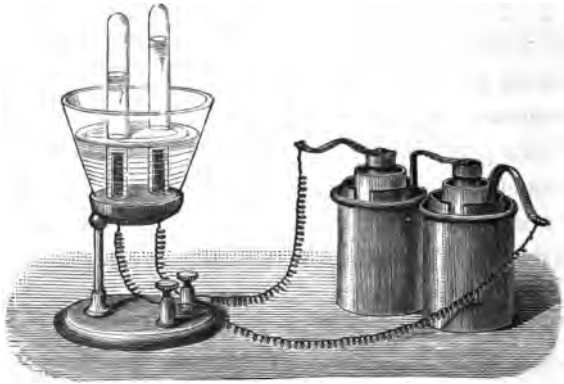


FIG. 196.

decomposed by forcing the current to traverse the solution. Substances which are thus decomposed are called *electrolytes;* the process is called *electrolysis;* the compound is said to be *electrolyzed.* The electrolysis of water is easily accomplished, affording a satisfactory qualitative and quantitative analysis of the liquid.

(*a.*) The apparatus consists of a vessel (Fig. 196) containing water (to which a little acid has been added to increase its conductivity) in which are immersed two platinum strips which constitute the two electrodes of a battery. When the circuit is closed, bubbles of oxygen escape from the positive electrode and bubbles of hydrogen from the negative. The gases may be collected separately by inverting over the electrodes tubes filled with water as shown in the figure. The volume of hydrogen thus collected will be twice as great as that of the oxygen.

398. Electrolysis of Salts.—Into a bent tube (known to

dealers in chemical glassware as a U tube) put a solution of any neutral salt, *e. g.*, sodium sulphate. Color the contents of the tube with the solution from purple cabbage. In the arms of the tube place the platinum electrodes of a battery as shown in Fig. 197. Close the circuit and presently the liquid at the + electrode will be colored red and that at the — electrode, green. If, instead of coloring the solution, a strip of blue litmus paper be hung near the + electrode it will be reddened, while a strip of reddened litmus paper hung near the — electrode will be colored blue. *These changes of color are chemical tests;* the appearance of the green or blue denotes the presence of an alkali (caustic soda in this case), while the appearance of the red denotes the presence of an acid.

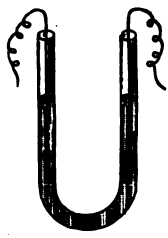


FIG. 197.

399. Electro-plating and Electro-gilding.— From the + pole of a galvanic battery suspend a plate of copper; from the — pole, suspend a silver coin. Place the copper and silver electrodes in a strong solution of copper sulphate. When the circuit is closed, the salt of copper is electrolyzed, the copper from the salt being

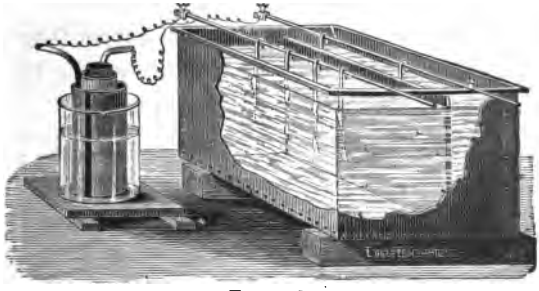


FIG. 198.

deposited upon the silver coin, the sulphuric acid going to the copper or + electrode as it did in the experiment described in the last paragraph. The silver is thus copper-plated.

(*a.*) If a solution of some silver salt be used and the direction of

the current be reversed, silver will be deposited upon the copper plate, which will thus be silver-plated. If the positive electrode be a plate of gold and the bath a solution of some salt of gold (cyanide of gold dissolved in a solution of cyanide of potassium), gold will be deposited upon the copper of the negative electrode, which will be thus electro-gilded.

400. Electrotyping.—Impressions are taken from type or engravings in wax, or any other plastic material that is impervious to water. A conducting surface is given to such a mould by brushing finely-powdered graphite over it, and it is then placed in a solution of sulphate of copper facing a copper plate. The mould is then connected with the + plate of a Galvanic battery and the copper with the — plate; when the circuit is closed, copper will be deposited upon the mould. When the copper film is thick enough (say as thick as an ordinary visiting card) it is removed from the mould, and strengthened by filling up its back with melted type-metal. The copper film and the type-metal are made to adhere by means of an amalgam of equal parts of tin and lead. The copper-faced plate thus produced is an exact reproduction of the type and engravings from which the mould was made.

Note.—It will be noticed that in all these cases the metal is carried in the direction of the current and deposited upon the negative electrode. In electro-plating and gilding, the technicalities of the art refer chiefly to the means of making the deposit firmly adherent. In electrotyping, they refer chiefly to the preparation of the mould or matrix. The countless applications of this process of depositing a thin metallic coat on a body prepared for its reception, constitute the important art of electro-metallurgy.

401. Electro-chemical Series.—The facts just considered suggest a division of substances into two classes, electro-positive and electro-negative. *The constituent of an electrolyte that goes to the negative electrode*

is called electro-positive; that which goes to the positive electrode is called electro-negative, these terms being based upon the idea of attraction between opposite electricities.

402. Physiological Effects of Voltaic Electricity.—The physiological effects are shocks and spasmodic muscular contractions more or less violent. When the electrodes of a strong battery, or the electrodes of a Ruhmkorff coil (§ 410), are held in moistened hands, the passage of the current through the body produces a peculiar sensation easily recognized thereafter. The current may be made to pass through a series of persons who have joined hands.

403. Induced Currents.—From our study of frictional electricity, we are familiar with the term *induction,* by which we understand the influence which an electrified body exerts upon a neighboring unelectrified body. In 1831, Faraday discovered an analogous class of phenomena produced by Voltaic electricity or by magnetism. *An induced current is an instantaneous current produced in a conductor by the influence of a neighboring current or magnet.* A current used to produce such an effect is called an inducing current.

404. Inductive Effect of Closing or Breaking a Circuit.—In Fig. 199, *B* represents a double coil made as follows: On a hollow cylinder of wood or card-board is wound several layers of stout copper wire, insulated by being covered with silk. The two ends of this wire, which constitute the *primary coil,* are seen dipping into the cups *gg'*. Upon this coil, and carefully insulated from it, is wound a much greater length of finer

copper wire, also silk covered. The two ends of this wire, which constitute the *secondary coil*, are seen connecting with the galvanometer *G*. Wires from the two plates of a Voltaic element dip into mercury in the cups *gg'*, thus closing an inducing circuit through the primary coil. While this circuit is closed, the galvanometer is at rest, showing that no current is passing through the secondary coil. By lifting one of the wires from one of the cups, the inducing current is interrupted. At this instant the galvanometer needle is deflected as by a sudden impulse,

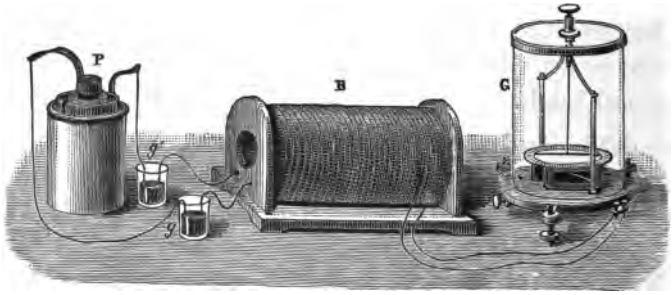


FIG. 199.

which immediately passes away. This shows the existence of an instantaneous induced current in the secondary coil. The direction in which the needle was turned, shows that the secondary current was direct, *i. e.*, that it had the same direction as the inducing current. If the wire just removed from the cup be replaced and the inducing current thus re-established, the galvanometer needle will be momentarily turned in the direction opposite to that in which it was previously turned. These experiments lead to this conclusion: *When a current begins to flow through the primary coil, it induces an inverse current in the secondary coil; when it ceases to flow through*

the primary coil, it induces a direct current in the secondary coil; both induced currents are merely instantaneous.

405. Currents Induced by Change of Distance.—If the primary coil be made movable, as shown in Fig. 200, and, with a current passing through it, be suddenly placed within the secondary coil, the galvanometer will show that an inverse current was induced in the outer coil. When the needle has come to rest, let the primary coil be removed, and the galvanometer will show that a direct current was induced. From this we see that *when the primary coil, bearing a current, is brought near the secondary coil, a momentary inverse current is induced in the latter; that when the coils are separated, a direct current is induced.*

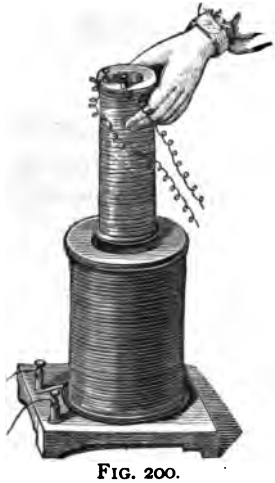


FIG. 200.

406. Magneto-electric Induction.—If, instead of the primary coil bearing the inducing current, a bar magnet be used, as shown in Fig. 201, the results produced will be like those stated in the last paragraph. *When the magnet is thrust into the interior of the coil, an induced current will flow while the motion of the magnet continues. When the magnet is stationary the current ceases to flow, and the needle gradually comes to rest. When the magnet is withdrawn, an induced current flows in the opposite direction.*

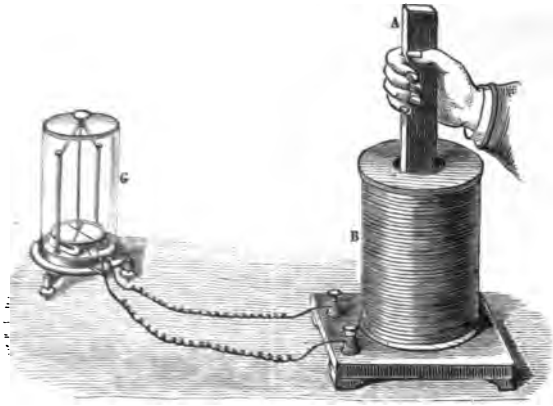


FIG. 201.

407. The Inductive Action of a Temporary Magnet.—If within the coil a soft iron bar (or still better, a bundle of straight soft, iron wires) be placed, as

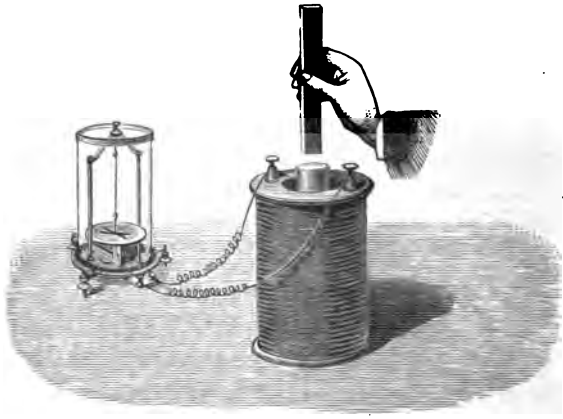


FIG. 202.

shown in Fig. 202, the induced current may be more effectively produced by bringing one end of a permanent

magnet near the end of the soft iron. In this case the induced currents are due to the magnetism of the soft iron, this magnetism being due to the inductive influence of the magnet (§ 311). Thus we see that *when the intensity of the magnetism of a bar of iron is increased or diminished, currents are induced in the neighboring coil.*

408. The Telephonic Current.—An electric current may be induced in a coil of insulated wire surrounding a bar magnet by the approach and withdrawal of a disc of soft iron. The disc *a* (Fig. 203) is magnetized by the inductive influence of the magnet *m* (§ 311). The disc, thus magnetized, reacts upon the magnet *m* and changes the distribution of magnetism therein. By varying the distance between *a* and *m*, the successive changes in the distribution of the magnetism of *m* induce to-and-fro currents in the surrounding coil.

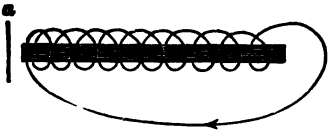


FIG. 203.

409. The Telephonic Circuit.—If the wire surrounding the magnet mentioned in the last paragraph be continued to a distance and then wound around a second bar magnet, as shown in Fig. 204, the currents induced at *A* would affect the magnetism of the bar at *B* (§ 392) or the intensity of its attraction for the neighboring disc *b*. A vibratory motion in the disc *a* would induce electric currents at *A*; these currents, when transmitted to *B*, would affect the magnetism of the bar there, and thus tend

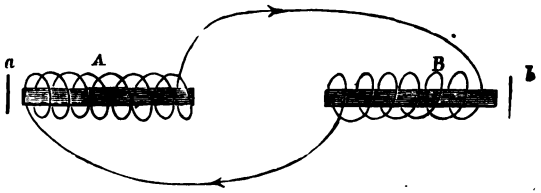


FIG. 204.

to produce exactly similar vibrations in *b*. "It is as if the close approach and quick oscillation of the piece of soft iron fretted or tantalized the magnet and sent a series of electrical shudders through the iron nerve."

(*a*.) We have here the principle of the telephone, so far as electric action is involved. Further consideration of this instrument must be deferred until we have learned more concerning sound. (See § 445.)

410. Ruhmkorff's Coil.—The induction coil, often called, from the name of its inventor, *Ruhmkorff's coil, is a contrivance for producing induced currents in a secondary coil by closing and opening, in rapid succession, the circuit of a current in the primary coil.*

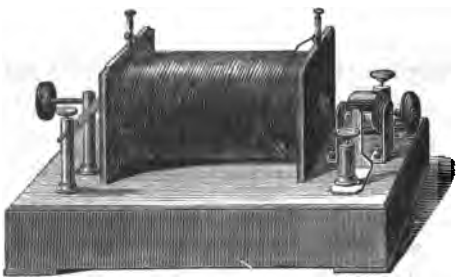


FIG. 205

The axis of the coils is a bundle of soft iron wires. These wires usually terminate in two small plates of soft iron which thus form the ends of the wire bundle. Around this bundle is wound the primary coil of insulated copper

wire about 2 *mm.* in diameter. Upon the primary coil, but carefully insulated from it, is wound the secondary coil. The wire of the secondary coil is very fine (about $\frac{1}{4}$ *mm.*) and many times longer than that of the primary. A hundred miles of wire has been put into a secondary coil.

(*a.*) The wire bundle becomes magnetized (§ 392) by the action of current in the primary coil, and then adds its inductive effect upon the secondary coil to that of the primary itself. The circuit is broken and closed by an automatic interrupter, represented at the left hand of the coil, Fig. 205. One of the posts there seen carries a metallic vibrating plate with an iron disc at its end. This plate vibrates back and forth between the end of the iron core of the coils and the end of the metal adjusting screw which is carried by the other post seen in the figure. These posts are in the circuit of the

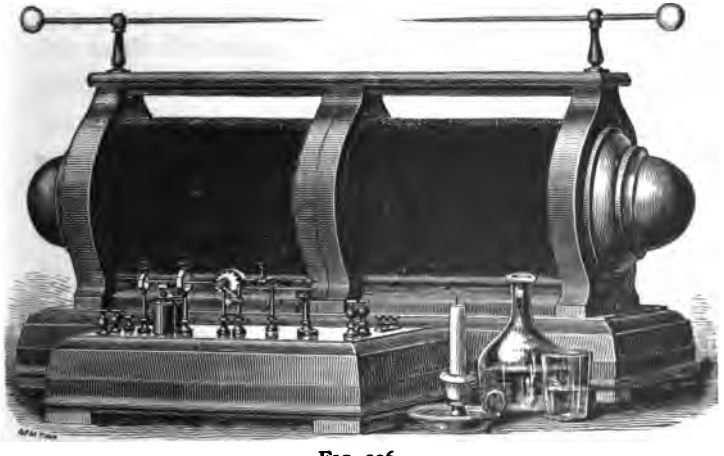


FIG. 206.

current passing through the primary coil. When the vibrating plate rests against the end of the adjusting screw, the circuit is closed and the iron core is magnetized. As soon as the core is magnetized, it attracts the iron disc at the end of the vibrating plate, thus drawing it away from the end of the screw and breaking the circuit. As soon as the circuit is broken, the bar is demagnetized and the plate, by virtue of its elasticity, springs back to

the screw, closing the circuit and again magnetizing the core. The plate is thus made to vibrate with great rapidity, each oscillation making or breaking the circuit of the inducing current, and thus creating a series of induced currents in the secondary coil (§ 404), which produce effects greater than can be produced by any electric machine. Fig. 206 represents an induction coil made by E. S. Ritchie, of Boston, for the U. S. Military Academy at West Point. In this instrument there is no automatic interrupter, the break-piece being operated by a ratchet-wheel and crank.

411. Spark from Induction Coil.—If the ends of the secondary coil be connected, opposite currents alternately traverse the connecting wire. When the ends are disconnected, as shown in Fig. 206, the inverse current cannot overcome the resistance of the intervening air because of its low electromotive power. *The direct current, produced by breaking the primary circuit, is alone able to force its way in the form of a spark.* The sparks vary with the power of the instrument. An induction coil has been made that gives a spark over 30 inches in length—a result incomparably greater than that obtainable from any electric machine. The induction coil may be used to produce any of the effects of frictional electricity, it being at the same time nearly free from the limitations which atmospheric moisture places upon all electric machines.

Note.—For an ordinary Ruhmkorff's coil, one to three Bunsen or potassium bi-chromate elements will suffice. The effect of the coil is generally increased by placing, in the base of the instrument, a condenser made of many sheets of tinfoil separated by layers of oiled silk. Alternate layers of the tinfoil are connected, *i. e.*, the first, third, fifth, seventh, etc., layers are connected, as also are the second, fourth, sixth, eighth, etc. The odd numbered layers are connected with one end of the primary coil; the even numbered layers with the other end. One object of this is to prevent the spark otherwise produced at the break-piece of the primary circuit.

412. Thermo-electricity.—*If a circuit be made*

of two metals and one of the junctions be heated or chilled, a current of electricity is produced.

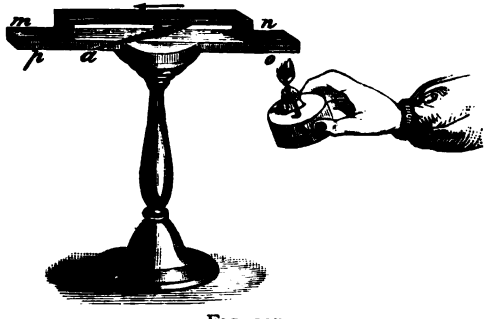


FIG. 207.

(*a.*) This may be illustrated by the apparatus shown in Fig. 207. The upper bar, *mn*, having its ends bent, is made of copper; the lower, *op*, is of bismuth. This rectangular frame is to be placed in the magnetic meridian and a magnetic needle placed within it. Upon heating one of the junctions a current will be produced, the existence of which is satisfactorily shown by the deflection of the needle as shown in the figure. The junction may be chilled with a piece of ice or by placing upon it some cotton wool moistened with ether. In this case a current, opposite in direction to the first, will be produced; the needle will be turned the other way (§ 390). (Appendix, L.)

413. A Thermo-electric Pair.—If a bar of antimony, *A*, be soldered to a bar of bismuth, *B*, and the free ends joined by a wire, as shown in Fig. 208, we evidently have a circuit equivalent to the one considered in the last paragraph. When the junction *C* is heated a current will pass from bismuth to antimony across the junction, and from antimony to bismuth through the wire.

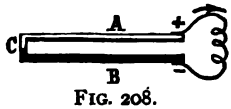


FIG. 208.

(*a*) The arrangement is analogous to the Voltaic element (§ 374), the antimony representing the − plate and carrying

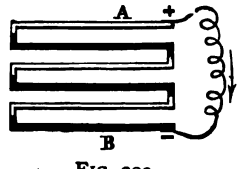


FIG. 209.

the + electrode, the bismuth representing the + plate and carrying the — electrode, while the solder takes the place of the liquid. Just as a number of Voltaic elements may be connected, so may a number of thermo-electric pairs, the arrangement being shown in Fig. 209.

414. The Thermo-electric Pile. — Several thermo-electric pairs, generally five, six, or seven, are arranged in a vertical series, as shown in Fig. 209, the intervening spaces being much reduced, the successive bars separated by strips of varnished paper only, and the wire connection omitted. A similar series may be united to this by soldering the free end of the antimony bar of one series to the free end of the bismuth bar of the other, the two series being separated by a strip of varnished paper. Any desirable number of such series may be thus united, compactly insulated, and set in a metal frame so that only the soldered ends are open to view. The free end of the antimony bar, representing the + electrode, and the free end of the bismuth bar, representing the — electrode, are connected with binding screws, which may be connected with a galvanometer. The complete apparatus, with the addition of conical reflectors, is called a thermo-electric pile or multiplier. It is shown in Fig. 210.

FIG. 210.

EXERCISES.

1. (*a.*) Draw a figure of a simple Voltaic element. (*b.*) State what is meant by the electric current. (*c.*) Indicate, upon the

figure, the direction of the current. (*d.*) What are the electrodes? (*e.*) Indicate them by their proper signs upon the figure.

2. (*a.*) Describe or figure a high resistance battery of Grove's elements. (*b.*) A low resistance battery of Bunsen's elements. (*c.*) What is the peculiar advantage of the Daniell's battery?

3. (*a.*) Describe an experiment illustrating the heating effects of current electricity. (*b.*) Describe the Voltaic arc.

4. (*a.*) How may a very feeble current be detected? (*b.*) Describe the apparatus used. (*c.*) Mention the features contributing to its delicacy.

5. (*a.*) How may a fire poker be temporarily magnetized with a magnet? (*b.*) Without a magnet? (*c.*) When temporarily magnetized without a magnet, what kind of a magnet does the poker become? (*d.*) State the principle of the electric telegraph.

6. (*a.*) How may an electric current be induced? (*b.*) What about the continuity of an induced current? (*c.*) Show how a magnet may produce the same effect as an electric current. (*d.*) Does this show that there is a fundamental connection between magnetism and electricity? (*e.*) Do the theories of magnetism and electricity connect satisfactorily the phenomena of magnetism and electricity?

7. (*a.*) What have we to show that there really is a fundamental connection between heat and electricity? (*b.*) Compare the Leyden battery, the Voltaic battery, and the lightning-flash with reference to their effects.

8. (*a.*) Define electrolyte. (*b.*) What term is applied to chemical decomposition when effected by means of an electric current? (*c.*) How would you go about the task of determining for yourself the electro-chemical nature of a substance?

Recapitulation.—In this section we have studied Electricity as produced by Chemical Action; the Electric Current and Circuit, and Electrodes; Voltaic Batteries; Amalgamating Battery Zincs; the Thermal and Luminous Effects of current Electricity, including the Electric Light; the deflection of the magnetic needle and the Galvanometer; Electro-Magnets and the Telegraph; Electrolysis; Electro-plating, and Electrotyping; the Physiological effects; Induced cur-

rents; the inductive effect of a Change of Distance of the inducing current; electric currents Induced by Magnets; Ruhmkorff's Coil; and the Thermo-electric pile.

Review Questions and Exercises.

1. (*a.*) Give the laws for pressure of liquids, and (*b.*) explain each by some fact or experiment.

2. (*a.*) What is a natural magnet? (*b.*) An artificial magnet? (*c.*) How does a magnet behave toward soft iron? (*d.*) How one magnet toward another magnet?

3. Give the facts in regard to the variation of the magnetic needle.

4. (*a.*) What are conductors in electricity? (*b.*) In what two ways may electrical separation be effected?

5. (*a.*) What conditions in the construction and erection of lightning-rods, are necessary to insure safety from lightning? (*b.*) Give the elements of a simple Galvanic cell, and (*c.*) the electric condition of those elements within and without the cell.

6. (*a.*) A body weighs at the surface of the earth 1024 lbs.; what would it weigh 1200 miles above the surface? (*b.*) Give the velocity of water issuing from an orifice, under a head of 81 feet. (*c.*) If 5 quarts of water weigh as much as 7 of alcohol, what is the specific gravity of the alcohol?

7. Find the kinetic energy of a 25 lb. ball that has fallen 3600 feet in vacuo.

8. Give the fundamental principle of Mechanics, and illustrate its application by one of the mechanical powers.

9. (*a.*) Over how high a ridge can you carry water in a siphon, where the minimum range of the barometer is 27 inches? (*b.*) Explain.

10. (*a.*) What is Specific Gravity? (*b.*) How do you find that of solids? (*c.*) What principle is involved in your method?

11. (*a.*) How much water per hour will be delivered from an orifice of 2 inches area, 25 feet below the surface of a tank kept full of water, not allowing for resistance? (*b.*) Give the law of magnetic attraction and repulsion.

12. (*a.*) State what you have been taught concerning the dipping needle. (*b.*) Define and illustrate magnetic induction.

13. (*a.*) Give the law of electric attraction and repulsion, and illustrate by the pith-ball electroscope. (*b.*) Define conductors and non-conductors, electrics and non-electrics. (*c.*) Illustrate by an example of each.

14. (*a.*) Explain (by figures) electric induction. (*b.*) Explain the charging of a Leyden jar. (*c.*) When charged, what is the electric condition of the outside and inside of the jar?

15. (*a.*) Give the sources of atmospheric electricity, and (*b.*) the effects of lightning.

16. (*a.*) What is the effect of breaking a magnet? (*b.*) Give a theory of magnetism that is competent to account for the properties of magnets, broken or unbroken.

17. (*a.*) How do soft iron and tempered steel differ as to susceptibility to magnetism? (*b.*) Describe one method of magnetizing a steel bar.

18. The influence of the earth's magnetism upon a magnetic needle is merely directive. (*a.*) Explain what this means. (*b.*) Show why it is so.

19. (*a.*) What is meant by electromotive force? (*b.*) Describe Grove's battery and its mode of action. (*c.*) Why are battery zincs generally amalgamated?

20. (*a.*) Describe Oersted's apparatus, and (*b.*) tell what its use teaches. (*c.*) Describe the construction of the astatic galvanometer.

21. (*a.*) Describe an electro-magnet, and (*b.*) tell what its advantages are. (*c.*) State the principle of the electric telegraph.

22. (*a.*) Describe a Ruhmkorff's coil, and (*b.*) explain its action.

23. (*a.*) Define electrolysis and electrolyte. (*b.*) Describe the electrolysis of water. (*c.*) Give a clear account of some branch of electro-metallurgy. (*d.*) What is meant by the terms *electro-positive* and *electro-negative*?

24. (*a.*) Define physics. (*b.*) Name and define the three conditions of matter. (*c.*) What do you understand by energy? (*d.*) Explain what is meant by foot-pound.

25. (*a.*) What condition of the atmosphere is desirable for experiments in frictional electricity? (*b.*) Why? (*c.*) How could you show, experimentally, that there are two opposite kinds of electricity?

26. (*a.*) Describe the experiment with Faraday's bag, and (*b.*) state what it teaches. (*c.*) Describe the dielectric machine, and (*d.*) explain its action.

27. In an air-pump, the capacity of the cylinder is one-fourth that of the receiver. Under ordinary atmospheric conditions, both together contain 62 grains of air. Find the capacity (*a.*) of the receiver, (*b.*) of the cylinder. After 5 strokes of the piston, (*c.*) how many grains of air would be left in the receiver? What would be its tension (*d.*) in pounds per square inch? (*e.*) In *Kg.* per *sq. cm.*? (*f.*) In inches of mercury?

28. (*a.*) Supposing we have two Leyden jars, one charged on the inside with positive electricity, and the other with negative on the inside; the two jars being insulated, can the jars be discharged by connecting the inner coats? (*b.*) Give reasons for your answer.

29. In a vessel having the dimensions of a cubic foot, sulphuric acid (sp. gr. = 1.83) stands eight inches high; give the pressure on the bottom and each side.

30. The lever of a hydrostatic press is six feet long, the fulcrum being at the end, and one foot from the piston rod. The diameter of the tube is one inch; that of the cylinder ten inches. The power is 25 lbs.; give the effect. (See Appendix A.)

31. What would a cubic foot of coal (sp. gr. = 2.4) weigh in a solution of potash (sp. gr. = 1.2)?

32. (*a.*) Define equilibrium and its kinds. (*b.*) Give examples. (*c.*) How does the centre of gravity of any system, acted upon by an exterior force, move? (*d.*) Give an example.

33. (*a.*) Figure a simple barometer. (*b.*) Explain why the mercury stands above its level. (*c.*) What atmospheric pressure will sustain a column of mercury 24 inches high?

34. (*a.*) How is it proved that air has weight? (*b.*) What is the weight of air in a room 30 ft. long, 20 ft. wide and 10 ft. high?

35. When a 1000 gram flask, containing 700 g. of water, was filled with the fragments of a mineral, it weighed 1450 grs. Give the specific gravity of the mineral.

36. A tank measuring 1 metre each way is filled with water: what will be the pressure on the bottom and sides?

37. (*a.*) What is meant by kinetic energy? (*b.*) By potential energy?

38. Two inelastic bodies are moving in opposite directions, one weighing 31 grams and having a velocity of 24 meters per second, the other weighing 22 grams and having a velocity of 18 meters per second: what is the united energy (*a.*) before, and (*b.*) after impact?

39. Regarding the same bodies as moving in the same direction, what would be the energy (*a.*) before, and (*b.*) after impact?

40. (*a.*) Draw a simple figure showing the essential parts of an air-pump, and (*b.*) explain the process of forming a vacuum. (*c.*) If the capacity of the barrel be $\frac{1}{4}$ that of the receiver, how much air will remain in the receiver at the end of the fourth stroke of the piston? and (*d.*) what would be its elastic force compared with that of the external air?

41. Discuss briefly the connection between electric separation and the more ordinary forms of energy.

CHAPTER VII.

SOUND.

SECTION I.

NATURE, REFRACTION AND REFLECTION OF SOUND.

415. Definition of Sound.—*Sound is that mode of motion which is capable of affecting the auditory nerve.*

(*a.*) The word sound is used in two different senses. It is often used to designate a *sensation* caused by waves of air beating upon the organ of hearing; it is also used to designate these aërial waves themselves. The former meaning refers to a physiological or psychological process; the latter to a physical phenomenon. If every living creature were deaf there could be no sound in the former sense, while in the latter sense the sound would exist but would be unheard. The definition above considers sound in the physical sense only.

416. Undulations.—In beginning the study of acoustics, it is very important to acquire a clear idea of the nature of undulatory motion. When a person sees waves approaching the shore of a lake or ocean, there arises the idea of an onward movement of great masses of water. But if the observer give his attention to a piece of wood floating upon the water, he will notice that it merely

rises and falls without approaching the shore. He may thus be enabled to correct his erroneous idea of the onward motion of the water. Again, he may stand beside a field of ripening grain, and, as the breezes blow, he will see a series of waves pass before him. But if he reflect and observe carefully, he will see clearly that there is no movement of matter from one side of the field to the other; the grain-ladened stalks merely bow and raise their heads. Most persons are familiar with similar wave movements in ropes, chains and carpets. *Each material particle has a motion, but that motion is vibratory, not progressive. The only thing that has an onward movement is the pulse or wave, which is only a form or change in the relative positions of the particles of the undulating substance.*

(*a.*) The motion of the wave must be clearly distinguished from the motion of particles which constitute the wave. The wave may travel to a great distance; the journey of the individual particle is very limited.

417. Wave Period.—When a medium is traversed by a series of similar waves, each particle is in a state of continued vibration. These vibrations are alike, they being as truly isochronous (§ 143) as those of the pendulum. *The time required for a complete vibration is called the period, and is the same for all the particles.*

418. Wave Length.—In such a series of similar waves, measuring in the direction in which the waves are travelling, *the distance from any vibrating particle to the next particle that is in the same relative position or "phase" is called a wave length.* In the case

of water waves, for example, the horizontal distance from one crest to the next crest would be a wave length.

419. Amplitude.—*Amplitude means the distance between the extreme positions of the vibrating particle,* or the length of its journey. As in the case of the pendulum, amplitude and period are independent of each other. Amplitude is also independent of wave length.

420. Relation of Period, Wave Length and Velocity.—During one period there will be one complete vibration, and the wave will advance one wave length. The velocity of the wave may be found by multiplying the wave length by the number of vibrations per second. Conversely, *the wave length may be found by dividing the velocity by the number of vibrations.*

421. Cause of Sound.—*All sound may be traced to the vibrations of some material body.* When a bell is struck, the edges of the bell are set in rapid vibration, as may be seen by holding a card or finger nail lightly upon the edge. The particles of the bell strike the adjacent particles of air, these pass the motion thus received on to the air particles next beyond, and these to those beyond.

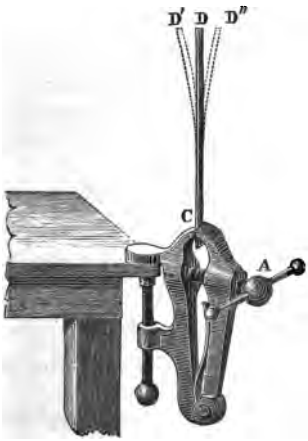


FIG. 211.

(*a.*) That sound is due to vibratory motion may be shown by numerous experiments. Holding one end of a straight spring, as a hickory stick, in a vise, pull the free

end to one side and let it go. Elasticity will return it to its position of rest, kinetic energy will carry it beyond, and so on, a vibratory motion being thus produced. When the spring is long, the vibrations may be seen. By lowering the spring in the vise, the vibrating part is shortened, the vibrations reduced in amplitude and increased in rapidity. As the spring is shortened, the vibrations become invisible but audible, showing that a sufficiently rapid vibratory motion may produce a sound.

(*b.*) Suspend a pith ball by a thread so that it shall hang lightly against one prong of a tuning-fork. When the fork is sounded, the pith ball will be thrown off by the vibrations of the prongs. Other illustrations of the same truth will be observed as we go on.

(*c.*) The vibrations of a tuning-fork may be made visible in the following manner: A glass plate which has been blackened by holding it in a petroleum flame is arranged so as to slide easily in the grooved frame *F*. A pointed piece of metal is attached to one

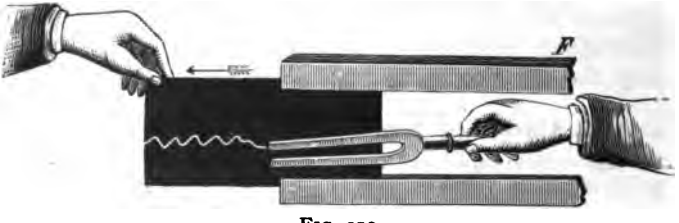


FIG. 212.

of the prongs of the fork. When the fork is made to vibrate, the point placed against the smoked plate and the plate drawn along rapidly in the grooves, the point traces on the glass an undulating line which represents fairly the vibratory movement of the prong.

422. Propagation of Sound.—Sound is ordinarily propagated through the air. Tracing the sound from its source to the ear of the hearer, we may say that the first layer of air is struck by the vibrating body. The particles of this layer give their motion to the particles of the next layer, and so on until the particles of the last layer strike upon the drum of the ear.

(*a.*) This idea is beautifully illustrated by Prof. Tyndall. He

imagines five boys placed in a row as shown in Fig. 213. "I suddenly push *A*; *A* pushes *B* and regains his upright position; *B* pushes *C*; *C* pushes *D*; *D* pushes *E*; each boy after the transmission of the push, becoming himself erect. *E*, having nobody in front, is thrown forward. Had he been standing on the edge of a precipice he would have fallen over; had he stood in contact with a window, he would have broken the glass; had he been close to a drum-head, he would have shaken the drum. We could thus transmit a push through a row of a hundred boys, each particular boy, however, only swaying to and fro. Thus also we send sound through the air, and shake the drum of a distant ear, while each particular particle of the air concerned in the transmission of the pulse makes only a small oscillation."

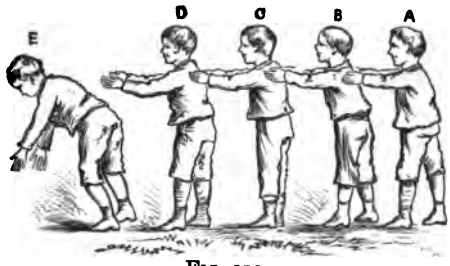


FIG 213.

423. Sound Waves.—The layers of air are crowded more closely together by each outward vibration of the

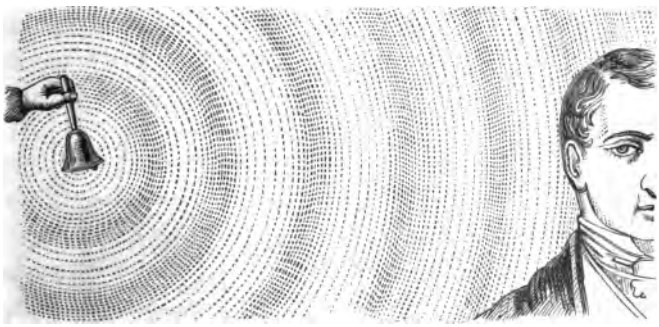


FIG. 214.

sounding body; a condensation of the air is thus produced. As the sonorous body vibrates in the opposite direction,

the nearest layer of air particles follows it; a rarefaction of the air is thus produced. *A sound wave, therefore, consists of two parts, a condensation and a rarefaction.* The motion of any air particle is backward and forward in the line of propagation, and not "up and down" across that line, as in the case of water waves. A series of complete sound waves consists of alternate condensations and rarefactions in the form of continually increasing spherical shells, at the common centre of which is the sounding body. Any line of propagation of the sound would be a radius of the sphere.

424. Sound Media.—The air particles impart their motion to other particles because of their elasticity. *Any elastic substance may become the medium for the transmission of sound, but such a medium is necessary.* The elasticity of a body may be measured by the resistance it opposes to compression. The less the compressibility, the greater the elasticity.

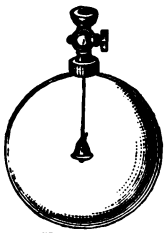


FIG. 215.

(*a.*) That sound is not transmitted in a vacuum is shown as follows: A large glass globe, provided with a stop-cock, contains a small bell suspended by a thread. When the air is pumped from the globe and the globe shaken, no sound is heard, although the clapper of the bell is seen to strike

FIG. 216.

against the bell. Readmitting the air, and again shaking the globe, the sound is plainly heard. (See Fig. 215.)

(*b*.) A small music box, or a clock-work arrangement for striking a bell (Fig. 216), may be supported upon a thick cushion of felt or cotton-batting, and placed under the capped receiver of an air-pump. When the receiver is exhausted, and the machinery started by the rod *g*, the motion may be seen but hardly any sound will be heard. If the support were perfectly inelastic and the exhaustion complete, no sound would be audible. The experiment may be made more perfect by filling the exhausted receiver with hydrogen and again exhausting the gas.

425. Velocity of Sound in Air.—It is a familiar fact that the transmission of sound is not instantaneous. The blow of a hammer is often seen several seconds before the consequent sound is heard; steam escaping from the whistle of a distant locomotive becomes visible before the shrill scream is audible; the lightning precedes the thunder. As we shall see further on, the time required for the propagation of light through terrestrial distances is inappreciable. Hence the interval between the two sensations of seeing and hearing is required for the transmission of the sound. This interval being observed and the distance being known, the velocity is easily computed. By such means it has been found that *the velocity of sound in air at the freezing temperature is about 332 m., or 1090 ft. per second.* There is some reason for believing that very loud sounds travel somewhat more rapidly than sounds of ordinary loudness. With this exception it may be said that, in a given medium, all sounds travel with the same velocity.

426. Velocity in Other Media.—*The velocity of sound depends upon two considerations—the elasticity and the density of the medium. It varies directly as the square root of the elasticity, and*

inversely as the square root of the density. At the freezing temperature, sound travels through oxygen with a velocity of 1040 feet, and through hydrogen with a velocity of 4164 feet per second.

$$v = \sqrt{\frac{E}{D}}.$$

(*a.*) It is a very common mistake to think that an increase of density causes an increase of velocity. It is known, *e.g.*, that sound travels more rapidly in water than in air; that water is more dense than air; hence, say the superficial, sound travels most rapidly in the densest bodies. *It does not follow.* Other things being equal, the denser the medium, the less the velocity of the motion. A little reflection will show that this must be so; experiments will verify the conclusion. *In wave motion, the particles of the medium constitute the thing that is moved.* With a given expenditure of energy, a number of light particles is moved more rapidly than an equal number of heavy particles (§ 157).

427. Effect of Temperature Upon Velocity.—An increase of the temperature of the air increases its elasticity and decreases its density. We might, therefore, expect sound to travel more rapidly in warm than in cold air. Experiment confirms the conclusion. *There is an added velocity of about 1.12 feet for every Fahrenheit degree, or of about 2 feet for every centigrade degree of increase of temperature.* (The freezing temperature is 32° F, or 0° C.)

428. Noise.—A noise may be momentary or continuous. A momentary noise consists of a single pulse in the medium produced by a single and sudden blow. It has neither period nor wave length. A continuous noise consists of an irregular and rapid succession of pulses. The ear is so constructed that its vibrations disappear very rapidly, but the disappearance is not instantaneous; if the

motion imparted to the auditory nerve by each individual pulse of the series continue until the arrival of its successor, the sound will not cease at all. *That the sound may be mere noise, the pulses must be irregular in their recurrence.*

(*a.*) Momentary noises may be produced by pounding with a hammer, stamping with the foot, clapping the hands, or drawing a stick slowly along the pickets of a fence. Continuous noises may be produced by sawing boards or filing saws. They are more or less familiar in the rattling of wheels over a stony pavement, the roar of waves, or the crackling of a large fire.

429. Music.—*A musical sound consists of a regular and rapid succession of pulses.* The regularity of the succession renders the sound smooth and agreeable; the rapidity renders it continuous. To secure this smoothness the pulses must be perfectly periodic; the sounding body must vibrate with the unerring regularity of the pendulum, but impart much sharper and quicker shocks to the air. Every musical sound has a well-defined period and wave length.

430. Elements of Musical Sounds.—Musical sounds or tones have three elements—intensity or loudness, pitch, and *timbre* or quality. The first two of these we shall consider at once, the third, a little further on.

431. Intensity and Amplitude.—*Intensity or loudness of sound depends upon the amplitude of vibration.* The greater the amplitude, the louder the sound.

(*a.*) If the middle of a tightly-stretched cord or wire, as a guitar string, be drawn aside from its position of rest and then set free, it will vibrate to and fro across its place of rest, striking the air and sending sound waves to the ear. If the middle of the string be drawn aside to a greater distance and then set free, the swing to and fro will be increased, harder blows will be struck upon the air,

and the air particles will move forward and backward through a greater distance. In other words, the amplitude of vibration has been increased. But this change in the aërial wave produces a change in the sensation. We still recognize the pitch to be the same as before; the tone is neither higher nor lower. We even recognize it still as being produced by a guitar string. The only difference is that the sensation is more intense; we say that the sound is louder.

432. Intensity and Distance.—*The intensity of sound varies inversely as the square of the distance from the sounding body.* Hence, the distance to which a sound may be heard depends upon its intensity.

FIG. 217.

433. Acoustic Tubes.—If the sound wave be not allowed to expand as a spherical shell, the energy of the wave cannot be diffused. This means that its intensity will be maintained. In acoustic tubes (Fig. 217) this diffusion is prevented; *the waves are propagated in*

only one direction. In this way, sound may be transmitted to great distances without considerable loss of intensity.

434. Pitch.—The second element of a musical sound is pitch, by which we mean the quality that constitutes the difference between a low or grave tone and a high tone. All persons are more or less able to recognize differences in pitch. A person who is able to judge accurately of the pitch of sounds is said to have a "good ear for music." *The pitch of a sound depends upon the rapidity of vibration of the sounding body,* or, in other words, upon the rate at which sound pulses follow each other. The more rapid the vibrations, the higher the tone.

435. Experimental Proof of the Cause of Pitch. — That pitch depends upon rapidity of vibration, may be roughly shown by drawing the finger nail across the teeth of a comb, slowly the first time and rapidly the second time. It may be shown more satisfactorily by means of Savart's wheel, shown in Fig. 218. This consists of a heavy brass ratchet-wheel, supported on an iron frame and pedestal. The wheel may be set in rapid revolution by a cord wound around the axis. By holding a card against the teeth, when in rapid motion, a shrill tone will be produced, gradually falling in pitch as the speed is lessened.

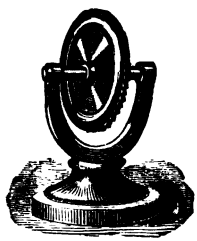


FIG. 218.

(*a.*) If the sounding body and the listening ear approach each other, the sound waves will beat upon the ear with greater rapidity. This is equivalent to increasing the rapidity of vibration of the

sounding body. The opposite holds true when the sounding body and the ear recede from each other. This explains why the pitch of the whistle of a railway locomotive is perceptibly higher when the train is rapidly approaching the observer, than when it is rapidly moving away from him.

436. Relation between Pitch and Period.—*Rate of vibration and period are reciprocals.* If the rate of vibration be 256 per second, the period is $\frac{1}{256}$ of a second. The period may, therefore, be used to measure the pitch; the greater the period, the lower the pitch.

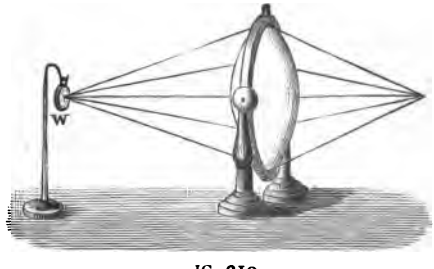
437. Relation between Pitch and Wave Length.—Since, in a given medium, all sounds travel with the same velocity, the rate of vibration determines the wave length. If the sounding body vibrate 224 times per second, 224 waves will be started each second. If the velocity of the sound be 1120 feet, the total length of these 224 waves must be 1120 feet, or the length of each wave must be five feet. If another body vibrate twice as fast, it will crowd twice as many waves into the 1120 feet; each wave will be only two and a half feet long. Thus wave length may be used to measure the pitch—the greater the wave length, the lower the pitch.

438. Refraction of Sound.—We have a clear idea of sound waves advancing as concentric, spherical shells, but we are far more familiar with the idea of sound advancing in definite straight lines. This idea is also correct, the lines being radii of the sphere. We may thus speak of lines or "rays" of sound, meaning thereby the direction in which the sonorous pulses are propagated. The ray is necessarily perpendicular to the wave. When the noise of the street is heard by a person in a closed room, the sound must have passed from the air without to the

solid matter of the walls, and from this to the air within. When sound thus passes obliquely from one medium to another, the rays are bent. *This bending of a sound ray is called refraction of sound.*

439. A Sound Focus.—Ordinarily, sound rays are divergent. The sound is therefore continually diminishing in intensity. By means of their refrangibility, they may be made convergent. If the divergent rays strike the side of a sack shaped like a double convex lens, made of two films of collodion, or very thin India rubber, and filled with carbonic acid gas (CO_2), their divergence will be diminished; they may thus be made parallel, or even convergent, after passing through the sack. At the point where these rays converge their total energy will be concentrated, and the intensity of the sound be thus increased. The point where the refracted rays intersect is called the focus of the lens. The laws of refracted sound are the same as those of refracted light, to be studied further on.

(*a.*) If a watch be hung near such a refractor, its ticking may be heard by placing the ear at the focus on the other side of the sack; when the sack is removed, the ticking is no longer audible. A few trials will enable the experimenter to determine the proper positions for the watch, the lens and the ear. The refraction directs to the ear all the energy exerted upon the anterior surface of the sack. This energy is sufficient to excite the sensation of hearing. A little reflection will show that when the sack is removed, the energy exerted upon the smaller surface of the tympanum at the



IG. 219.

greater distance is very much diminished. This lesser energy is unable to excite the auditory nerve to action, and the ticking of the watch is unheard.

440. Reflection of Sound.—When a sound ray strikes an obstacle, it is reflected in obedience to the principle given in § 97. This fact is turned to account in the case of "conjugate reflectors" of sound. Fig. 220 represents the section of two parabolic reflectors *mn* and *op*. It is a peculiarity of such reflectors that rays starting from the focus, as *F*, will be reflected as parallel rays, and that parallel rays falling upon such a reflector will converge at the focus, as *F'*. Hence, two such reflectors may be placed in such a position that sound waves starting from one focus shall, after two reflections, be converged at the other focus. *Two reflectors so placed are said to be conjugate to each other.* This principle underlies the phenomena of whispering galleries.

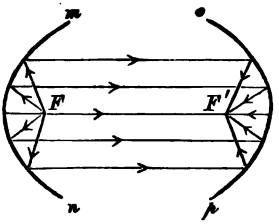


FIG. 220.

(*a.*) "The great dome of St. Paul's Cathedral in London is so constructed that two persons at opposite points of the internal gallery, placed in the drum of the dome, can talk together in a mere whisper. The sound is transmitted from one to the other by successive reflections along the course of the dome." A similar phenomenon is observable in the dome of the Capitol at Washington.

441. Experiment.—At the focus of a curved reflector, place a watch or other suitable sounding body. Directly facing it, but at a distance so great that the ticking is unheard, place a similar reflector. When the ear is placed at the focus of the second mirror, as shown in Fig. 221, the ticking is plainly heard.

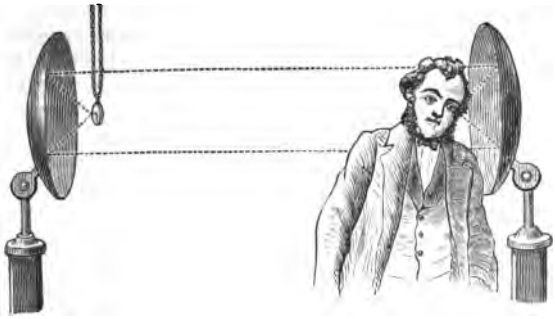


FIG. 221.

(*a.*) In the experiment above described, it is plain that many of the rays reflected by the first mirror are intercepted before they reach the second mirror. This may be remedied, in part, by the use of an ear-trumpet, the larger end being held at the focus of the second reflector. The ear-trumpet may be a glass funnel, with a piece of rubber tubing leading from its smaller end to the ear. The experiment may be modified by using a single reflector, the watch being placed a little further from the reflector. The proper positions for the watch and the funnel are easily determined by experiment. They are *conjugate foci* (§ 602).

442. Echo.—*When a sound, after reflection, is audible, it is called an echo.* The distinctness with which it is heard depends upon the distance of the ear from the reflecting surface. A very quick, sharp sound may produce an echo even when the reflecting surface is not more than fifty or sixty feet away, but for articulate sounds a greater distance is necessary.

(*a.*) Few, if any, persons can pronounce distinctly more than about five syllables in a second. At the ordinary temperature, sound travels about 1120 feet per second. In a fifth of that time it would travel about 224 feet. If, therefore, the reflecting surface be 112 feet distant, the articulate sound will go and return before the next syllable is pronounced. The two sounds will not interfere, and the echo will be distinctly heard. If the reflecting surface be less than this distance, the reflected sound will return before

the articulation is complete and confusedly blend with it. If the reflector be 224 feet distant, there will be time to pronounce two syllables before the reflected wave returns. The echo of both syllables may then be heard; and so on. The echo may be heard sometimes when the direct sound cannot be heard.

(*b.*) Suppose the speaker to stand 1120 feet from the reflecting substance. If then he speak ten syllables in two seconds, the echo of the first will return just as the last is spoken; the echo of each syllable will be distinct. But if he continues to speak, the direct and the reflected sounds will become blended and confused. The reflecting surface should be a large, vertical wall, or similar object, as a huge rock.

(*c.*) When two opposite surfaces, as parallel walls, successively reflect the sound, *multiple echoes* are heard. Sometimes an echo is thus repeated 20 or 30 times.

EXERCISES.

1. If 18 seconds intervene between the flash and report of a gun, what is its distance, the temperature being 82° F.?

2. What will be the length of the sound waves propagated through air at a temperature of 15° C. by a tuning-fork that vibrates 224 times per second?

3. State clearly the difference between a transverse and a longitudinal wave.

4. Determine the temperature of the air when the velocity of sound is 1150 feet per second.

5. If A is 50 *m.* from a bell, and B is 70 *m.* from it, how will the loudness of the sound as heard by B compare with the loudness as heard by A?

6. A shot is fired before a cliff, and the echo heard in six seconds. The temperature being 15° C. find the distance of the cliff.

7. A certain musical instrument makes 1100 vibrations per second. Under what conditions will the sound waves be each a foot long?

8. How many vibrations per second are necessary for the formation of sound waves four feet long, the velocity of sound being 1120 feet? What will be the temperature at the time of the experiment?

9. Taking the velocity of sound as 332 *m.*, find the length of a wave if there are 830 vibrations per second.

10. The waves produced by a man's voice in common conversation are from eight to twelve feet long. If the velocity of sound be

1128 feet, find the corresponding numbers of vibrations of vocal chords.

11. A person stands before a cliff and claps his hands. In $\frac{1}{5}$ of a second he hears the echo. How far distant was the cliff?

Recapitulation.—In this section we have considered the Definition of sound; Undulations; the Period, Length and Amplitude of waves; the Cause and Propagation of sound; sound Waves and Media; the Velocity in air and in other media, and the effect of Temperature; the difference between Noise and Music; the Three Elements of musical sounds; the relation of Loudness to amplitude and distance; Acoustic Tubes; the cause of differences in Pitch; the relation that exists between Pitch and Period, or Wave Length; Refraction and Foci of sound; Reflection of sound; Echoes.

SECTION II.

COMPOSITION OF SOUND WAVES; MUSICAL INSTRUMENTS.

443. Sympathetic Vibrations.—The string of a violin may be made to vibrate audibly by sounding near it a tuning-fork of the same tone. By prolonging a vocal tone near a piano, one of the wires seems to take up the note and give it back of its own accord. If the tone be changed, another wire will give it back. In each case, that wire is excited to audible action, which is able to

vibrate at the same rate as do the sonorous waves that set it in motion. Thus the vibrations of the strings may produce sonorous waves, and the waves in turn may produce vibrations in another string. The most important feature of the phenomenon is that *the string absorbs only the particular kind of vibration that it is capable of producing.* (Read Tyndall "On Sound," pp. 323–5.)

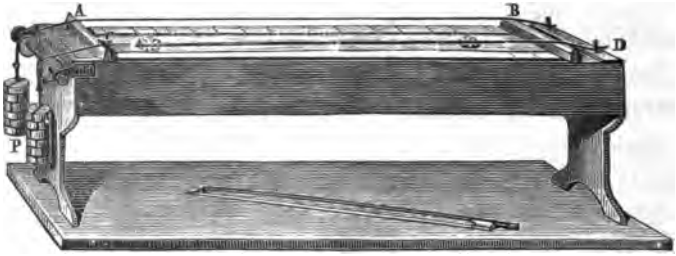


FIG. 222.

(*a.*) Tune to unison two strings upon the same sonometer (Fig. 222). Upon one string place two or three paper riders. With a violin bow, set the other string in vibration. The sympathetic vibrations thus produced will be shown by the dismounting of the riders, whether the vibrations be audible or not. Change the tension of one of the strings, thus destroying the unison. Repeat the experiment and notice that the sympathetic vibrations are not produced.

(*b.*) Place several feet apart two tuning-forks mounted upon resonant cases. The forks should have the same tone, and the cases should rest upon pieces of rubber tubing to prevent the transferrence of vibratory motion to and through the table. Sound the first fork by rapidly separating the two prongs with a rod. Notice the pitch. At the end of a second or two touch the prongs to stop their motion and sound. It will be found that the second fork has been set in motion by the repeated blows of the air, and is giving forth a sound of the same pitch as that originally produced by the first fork. Fasten, by means of wax, a 3-cent silver piece or other small weight to one of the prongs of the second fork. An attempt to repeat the experiment will fail.

FIG. 223.

(*c.*) When the two forks are in unison, their periods are the same. The second and subsequent pulses sent out by the first fork strike the second fork, already vibrating from the effect of the first pulse, in the same phase of vibration, and thus each adds its effect to that of all its predecessors. If the forks be not in unison, their periods will be different and but few of the successive pulses can strike the second fork in the same phase of vibration; the greater number will strike it at the wrong instant.

444. Sounding-Boards.—In the case of the sonometer, piano, violin, guitar, etc., the sound is due more to the vibrations of the resonant bodies that carry the strings than to the vibrations of the strings themselves. The strings are too thin to impart enough motion to the air to be sensible at any considerable distance; but as they vibrate, their tremors are carried by the bridges to the material of the sounding apparatus with which they are connected.

(*a.*) This sounding apparatus usually consists of thin pieces of wood which are capable of vibrating in any period within certain limits. The vibrations of these large surfaces and of the enclosed air produce the sonorous vibrations. The excellence of a Cremona violin does not lie in the strings, which may have to be replaced daily. The strings are valuable *to determine the rate of vibration* that shall be produced (§ 455). The excellence of the instrument depends upon the sonorous character of the wood, which seems to improve with age and use.

(*b.*) Similar remarks apply to the tuning-fork, When a tuning-fork held in the hand is struck, but a feeble sound is heard. When the handle is placed upon the table or almost any solid having a considerable surface, the intensity of the sound is remarkably increased. Hence, for class or lecture experiments, tuning-forks should be mounted as shown in Fig. 223.

Note.—Before beginning the study of the telephone, the pupil should carefully review §§ 408, 409.

445. The Telephone.—This instrument is represented in section by Fig. 224. *A* is a permanent bar

magnet, around one end of which is wound a coil, *B*, of fine copper wire carefully insulated. The ends of this coiled wire are attached to the larger wires *CC*, which communicate with the binding posts *DD*. In front of the magnet and coil is the soft iron diaphragm *E*, which corresponds to the disc *a*, of Fig. 203. The distance between *E* and the end of *A* is delicately adjusted by the screw *S*. In front of the diaphragm is a wooden mouth-piece with a hole about the size of a dime, at the middle of the diaphragm and opposite the end of the magnet. The outer case is made of wood or hard rubber. The external appearance of the complete instrument is represented by Fig. 225. The binding posts of one instrument being connected by wires with the binding posts of another at a distance, conversation may be carried on between them.

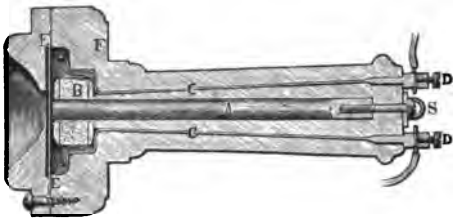


FIG. 224.

FIG. 225.

446. Action of the Telephone.—When the mouth-piece is brought before the lips of a person who is talking, air waves beat upon the diaphragm and cause it to vibrate. The nature of these vibrations depends upon the loudness, pitch, and *timbre* of the sounds uttered. Each vibration of the diaphragm induces

an electric current in the wire of *B*. These currents are transmitted to the coil of the connected telephone, at a distance of, perhaps, several miles, and there produce, in the diaphragm of the instrument, vibrations exactly like the original vibrations produced by the voice of the speaker. These vibrations of the second diaphragm send out new air waves that are very faithful counterparts of the original air waves that fell upon the first diaphragm. The two sets of air waves being alike, the resulting sensations produced in the hearers are alike. Not only different words but also different voices may be recognized. The arrangement being the same at both stations, the apparatus works in either direction.

(*a.*) The reproduced sound is somewhat feeble but remarkably clear and distinct. The second telephone should be held close to the ear of the listener. Sometimes there are, in the same circuit, two or more instruments at each station, so that each operator may hold one to the ear and the other to the mouth ; or the listener may place one at each ear. When the stations are a considerable distance apart, one binding post of each instrument may be connected with the earth, as in the case of the telegraph (§ 395).

(*b.*) It is to be distinctly noticed that the *sound waves* are not transmitted from one station to the other. "The air waves are spent in producing mechanical vibrations of the metal ; these create magnetic disturbances which excite electrical action in the wire, and this again gives rise to magnetic changes that are still further converted into the tremors of the distant diaphragm, and these finally reappear as new trains of air waves that affect the listener."

447. The Phonograph.—This is an instrument for recording sounds and reproducing them after any length of time.

(*a.*) The receiving apparatus consists of a mouth-piece and vibrating disc like those of the telephone. At the back of the disc is a short needle or style for recording the vibrations upon a sheet of tinfoil moving under it. This tinfoil is placed upon a metal

cylinder about a foot (30 *cm.*) long. The cylinder has a spiral groove upon its curved surface and a similar thread upon its axis, which turns in a fixed nut. As the cylinder is turned by a crank, the threads upon the axis give the cylinder a lengthwise motion. The style is placed in position over one of the tinfoil covered grooves of the cylinder. As the cylinder revolves, a projection in front of the style crowds the foil down into the groove. The needle follows in the channel thus made, and, as it vibrates, records a succession of dots in the tinfoil. *These dots constitute the record.* To the naked eye they look alike, but the microscope reveals differences corresponding to pitch, loudness, and *timbre.*

(*b.*) To reproduce the sound, the style is lifted from the foil, the cylinder turned back to its starting-point, the style placed in the beginning of the groove, and the crank turned. The style passes through the channel and drops into the first indentation; the disc follows it. The style rises and drops into each of the succeeding indentations, the disc following its every motion with a vibration. The original vibrations made the dots; the dots are now making similar vibrations. Sound waves made the original vibrations; now the reproduced vibrations create similar sound waves. The reproduced sounds are a little muffled but perfectly distinct, each of the three qualities (§ 430) being recognizable. The principle may be applied to any implement or toy that makes a sound as well as to the voice. Perfectly simple; equally wonderful.

448. Coincident Waves.—In the case of water waves, when crest coincides with crest the water reaches a double height. So with sound waves, when condensation coincides with condensation, this part of the wave will be more condensed; when rarefaction coincides with rarefaction, this part of the wave will be more rarefied. This increased difference of density in the two parts of the wave means increased loudness of the sound, because there is an increased amplitude of vibration for the particles constituting the wave.

449. Reinforcement of Sound.—This increased intensity may result from the blending of two or more series of similar waves in like phases, or from the union of

direct and reflected waves in like phases. Under such circumstances, one set of waves is said to reinforce the other. The phenomenon is spoken of as the reinforcement of sound.

450. Resonance.—Resonance is a variety of the reinforcement of sound due to sympathetic vibrations. The resonant effects of solids were shown in § 444. The resonance of an air column is well shown by the following experiments:

(*a.*) When a sounding tuning-fork is held over the mouth of a glass jar, 18 or 20 inches deep, a feeble sound is heard. By carefully pouring in water, we notice that when the liquid reaches a certain level, the sound suddenly becomes much louder. The water has shortened the air column until it is able to vibrate in unison with the fork. If more water be now poured in, the intensity of the sound is lessened. If a fork of different vibration be used, the column of air that gives the maximum resonance will vary, the air column becoming shorter as the rate of vibration of the fork increases. The length of the air column is one-fourth the length of the wave produced by the fork. *Why?*

FIG. 226.

(*b.*) Fig. 227 represents Savart's bell and resonator. The bell, on being rubbed with the bow, produces a loud tone. The resonator is a tube with a movable bottom. The length of the resonant air column is changed by means of this movable bottom. The point

at which the reinforcement of sound is greatest is easily found by trial. If, when the sound of the bell has become hardly audible, the tube be brought near, the resonant effect is very marked.

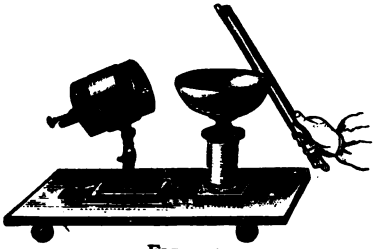


FIG. 227.

451. Interference of Sound.—If, while a tuning-fork is vibrating, a second fork be set in vibration, the waves from the second must traverse the air set in motion by the former. If the waves from the two forks be of equal length, as will be the case when the two

FIG. 228.

forks have the same pitch, and the forks be any number of whole wave lengths apart, the two sets of waves will unite in like phases (Fig. 228), (condensation with condensation,

FIG. 229.

etc.), and a reinforcement of sound will ensue. But if the second fork be placed an odd number of half wave lengths behind the other, the two series of waves will meet in opposite phases; where the first fork requires a condensation, the second will require a rarefaction. The two sets

of waves will interfere, the one with the other. If the waves be of equal intensity, the algebraic sum of these component forces will be zero. The air particles, thus acted upon, will remain at rest; this means silence. In Fig. 229, an attempt is made to represent this effect to the eye, the uniformity of tint indicating the absence of condensations and rarefactions. *Thus, by adding sound to sound, both may be destroyed. This is the leading characteristic property of wave motion. The phenomenon here described is called interference of sound.*

FIG. 230.

(*a.*) The sound of a vibrating tuning-fork held in the hand is almost inaudible. The feebleness results largely from interference. As the prongs always vibrate in opposite directions at the same time, one demands a rarefaction where the other demands a condensation. By covering one vibrating prong with a pasteboard tube the sound is more easily heard. (Fig. 230.)

(*b.*) Hold a vibrating tuning-fork near the ear, and slowly turn it between the fingers. During a single complete rotation, four

positions of full sound and four positions of perfect silence will be found. When a side of the fork is parallel to the ear, the sound is plainly audible; when a corner of a prong is turned toward the ear, the waves from one prong completely destroy the waves started by the other. The interference is complete.

(*c.*) Over a resonant jar, as shown in Fig. 226, slowly turn a vibrating tuning-fork. In four positions of the fork we have loud, resonant tones; in four other positions we have complete interference. If, while the fork is in one of these positions of interference, a pasteboard tube be placed around one of the vibrating prongs, a resonant tone is instantly heard; the cause of the interference has been removed.

452. Beats.—If two tuning-forks, *A* and *B*, vibrating respectively 255 and 256 times a second, be set in vibration at the same time, their first waves will meet in like phases and the result will be an intensity of sound greater than that of either. After half a second, *B* having gained half a vibration upon *A*, the waves will meet in opposite phases and the sound will be weakened or destroyed. At the end of the second we shall have another reinforcement; at the middle of the next second another interference. *This peculiar palpitating effect is due to a succession of reinforcements and interferences, and is called a beat.* The number of beats per second equals the difference of the two numbers of vibrations.

(*a.*) In a quiet room, strike simultaneously one of the lower white keys of a piano and the adjoining black key. The beats will be heard.

(*b.*) If the two tuning-forks described in § 443, one being loaded as there mentioned, be simultaneously sounded, the beats will be very perceptible. Replacing the 3-cent piece successively by a silver half-dime and a dime, the number of beats will be successively increased.

(*c.*) If two large organ pipes, having exactly the same tone, be simultaneously sounded, a low, loud, uniform sound will be produced. If an aperture be made in the upper part of one of the walls of one of the pipes and closed by a movable plate, the tone

produced by the pipe may be changed at will. The more the aperture is opened, the higher the pitch. In this manner, *slightly* raise the pitch of one of the pipes. If the pipes be sounded in succession, even a trained ear would probably fail to detect any difference. If they be sounded simultaneously, the sound will be of varying loudness, very marked jerks or palpitations being perceptible.

453. Practical Effect of Beats.—The human ear may recognize about 38,000 different sounds. If a string, for example, vibrating 400 times per second were sounded, and one vibrating 401 times per second were *subsequently* sounded, the ear would probably fail to detect any difference between them. But if they were sounded simultaneously, the presence of one beat each second would clearly indicate the difference. Unaided by the beats, the ear can detect about one per cent. of the 38,000 sounds lying within the range of the human ear. Beats are, therefore, very important to the tuner of musical instruments. To bring two slightly different tones into unison, he has only to tune them so that the beats cease.

454. Vibrations of Strings.—The laws of musical tones are most conveniently studied by means of stringed instruments. In the violin, etc., the strings are set in vibration by bowing them. The hairs of the bow, being rubbed with rosin, adhere to the string and draw it aside until slipping takes place. In springing back, the string is quickly caught again by the bow and the same action repeated. In the harp and guitar, the strings are plucked with the finger. In the piano, the wires are struck by little leather-faced hammers worked by the keys. The vibrations of the string, and consequently the pitch, depend upon the string itself. The manner of producing the vibrations has no effect upon the pitch.

455. Laws of the Vibrations of Strings.—The following are important laws of musical strings:

(1.) Other conditions being the same, the number of vibrations per second varies inversely as the length of the string.

(2.) Other conditions being the same, the number of vibrations per second varies directly as the square root of the stretching weight, or tension.

(3.) Other conditions being the same, the number of vibrations per second varies inversely as the square root of the weight of the string per linear unit.

(*a.*) All of these laws may be roughly illustrated by means of a violin. The length of the string may be altered by fingering; the tension may be changed by means of the screws or keys; the effects of the third law may be shown by the aid of the four strings.

(*b.*) For the illustration of these laws the sonometer, shown in Fig. 231, is generally used. The length of the string is determined

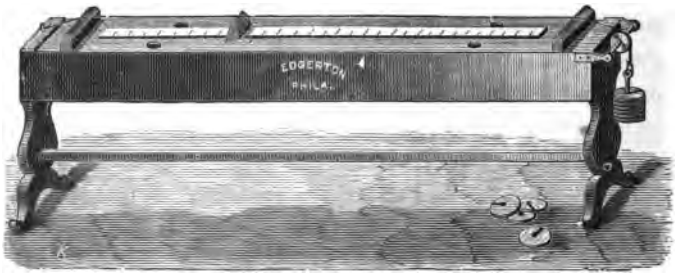


FIG. 231.

by the two fixed bridges, or by one of them and the movable bridge which may be employed for changing the length of the vibrating part of the string; the tension is regulated by weights, which may be changed at pleasure; the third law may be verified by using different strings of known weights. Iron and platinum wires of the same diameters are frequently used for this purpose.

(*c.*) From these laws it follows, for example, that a string of half the length, or four times the tension, or one-fourth the weight of a given string will vibrate just twice as fast as the given string, *i.e.*, twice as fast on account of *any one* of these three variations. A string of one-third the length, or nine times the tension, or one-ninth the weight of a given string, will vibrate three times as fast as the given string; and so on.

456. The Musical Scale.—Starting from any

arbitrary tone or absolute pitch, the voice rises or falls in a manner very pleasing to the ear, by eight steps or intervals. The whole series of musical tones may be divided into octaves, or groups of eight tones each, the relation between any two members of one group being the same as the relation between the corresponding members of any other group. The eighth of the first group becomes the first of the second. The intervals between the successive tones are not precisely the same, as will be seen from the next paragraph.

457. Relative Numbers of Vibrations.—A string vibrating half as rapidly as a given string, will give its octave below; one vibrating twice as rapidly, its octave above. The ratio of the number of vibrations corresponding to the interval of an octave is, therefore, 1 : 2. The relative number of vibrations corresponding to the tones which constitute the major diatonic scale (gamut) are as follows:

Relative Names,	1,	2,	3,	4,	5,	6,	7,	8.
Absolute Names,	C,	D,	E,	F,	G,	A,	B,	C.
Syllables,	*do,*	*re,*	*mi,*	*fa,*	*sol,*	*la,*	*si,*	*do.*
Relative Numbers of Vibrations,	1,	$\frac{9}{8}$,	$\frac{5}{4}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{5}{3}$,	$\frac{15}{8}$,	2.
" " "	24,	27,	30,	32,	36,	40,	45,	48.

458. Absolute Numbers of Vibrations.—Knowing the number of vibrations which constitute the tone called *do,* the absolute number of vibrations of any of the other tones of the scale may be obtained by multiplying the number of vibrations of *do* by the ratio between it and that of the given tone as shown above. Thus, if *C* have 256 vibrations per second, *G* will have $256 \times \frac{3}{2} = 384$

vibrations per second; its octave will have 512; the fifth of its octave will have $512 \times \frac{3}{2} = 768$. If F be given 352 vibrations, C will have $352 \div \frac{4}{3} = 264$. Thus, knowing C, any given tone may have its number of vibrations determined by multiplying by the proper ratio.

459. Absolute Pitch.—The number of vibrations constituting the tone called C is purely arbitrary. The assignment of 256 complete vibrations to middle C is common, but the practice of musicians is not uniform. A certain tuning-fork deposited in the Conservatory of Music at Paris is the standard for France; it assigns 261 vibrations per second to middle C. The standard tuning-fork adopted by English musicians and deposited with the Society of Arts in London, gives 264 vibrations to middle C. Multiplying the numbers in the last line of §457 by 11, we shall have the absolute numbers of vibration for the several tones of the gamut corresponding to this standard.

(*a.*) Whatever be the standard thus adopted, an instrument will be in tune when the *relative* number of vibrations is correct. The string that produces the tone G must always vibrate three times while the one producing C vibrates twice, or 36 times, while the latter vibrates 24 times. While the string yielding D vibrates 27 times, the string yielding B must vibrate 45 times; and so on.

(*b.*) Middle C is the tone sounded by the key of a piano at the left of the two black keys near the middle of the key-board. It is designated by C_1. Its octaves below and above are designated as follows:

$$C_{-2},\quad C_{-1},\quad C,\quad C_1,\quad C_2,\quad C_3,\quad C_4.$$

460. Fundamental Tones and Overtones.—A string may vibrate transversely as a whole, or as independent segments. Such segments will be aliquot parts of the whole string, and separated from each other by points

of no motion, called nodes or nodal points. *The tone produced by the vibrations of the whole length of a string is called its fundamental tone. The tones produced by the vibrations of the segments of a string are called its overtones or harmonics.*

(*a.*) The fact that a string may thus vibrate in segments, with the further fact that a string, or other sounding body, can hardly be made to vibrate as a whole without vibrating in segments at the same time, furnishes a means of explaining quality or *timbre* of sound. (§ 430.)

461. Fundamental Tones.—When a string vibrates so as to produce its fundamental tone, its extreme positions may be represented by the continuous and the dotted lines of Fig. 232.

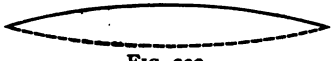


FIG. 232.

This effect is obtained by leaving the string free and bowing it near one of its ends. If a number of little strips of paper, doubled in the middle, be placed like riders upon the string, and the string bowed as just described, all of the riders will be thrown up and most of them off. This shows that the whole string vibrates as one string; that there is no part of it between the fixed ends that is not in vibration.

462. The First Overtone.—If the string of the sonometer be touched exactly at its middle with a finger, or better, with a feather, a higher tone is produced when the string is bowed. This higher tone is the octave of the fundamental. The string now vibrates in such a way that the point touched remains at rest. Its extreme positions may be represented by the lines of Fig. 233. The point *N* is acted upon by two equal and opposite forces; it is urged to move both

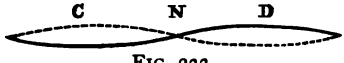


FIG. 233.

ways at the same time, and, consequently, does not move at all, but remains at rest as a node. The tone is due to the vibrations of the two halves of the string, which thus give the octave instead of the fundamental. The existence of the node and segments will continue for some time after the finger is removed. If riders be placed at *C*, *N* and *D*, the one at *N* will remain at rest while those at *C* and *D* will probably be dismounted.

463. Higher Overtones.—In like manner, if the vibrating string be touched at exactly one-third, one-fourth

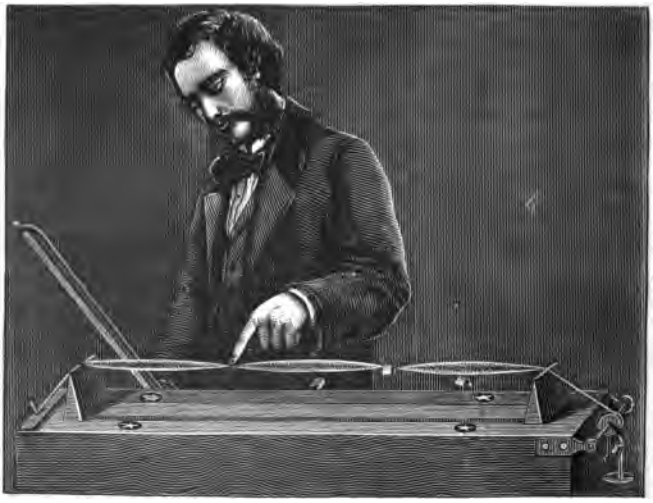


FIG. 234.

or one-fifth of its length from one end, it will divide into three, four or five segments, with vibrations three, four or five times as rapid as the fundamental vibrations. If touched at one-third its length, as represented in Fig. 234, the tone will be the fifth to the octave of the fundamental;

if touched at one-fourth its length, the tone will be the second octave above. Of course, any other aliquot part of the length of the string may be used. In any case, the experiment with riders may be repeated to indicate the position of the segments and nodes.

464. Quality or Timbre.—As a sounding body vibrates as a whole and in segments at the same time, the fundamental and the harmonics blend. The resultant effect of this blending of fundamentals and harmonics constitutes what we call the quality or *timbre* of the sound. We recognize the voice of a friend not by its loudness nor by its pitch, but by its quality. When a piano and violin sound the same tone, we easily distinguish the sound of one from that of the other, because, while the fundamentals are alike, the harmonics are different. Hence, *the total effects* of the fundamentals and the harmonics, or the qualities, are different. The possible combinations of fundamentals and harmonics, or forms of vibratory motion, are innumerable.

Note.—The pupil is advised to read the section on *Harmonics* in the third of Tyndall's Lectures *On Sound*, pp. 116–124. Become the owner of the book, if you can.

465. Classes of Musical Instruments.—Musical instruments may be divided into two classes, stringed instruments and wind instruments. The sounds sent forth by stringed instruments are due to the regular vibrations of solids; those sent forth by wind instruments, to the regular vibrations of columns of air confined in sonorous tubes.

466. Sonorous Tubes.—The material of which a sonorous tube is made does not affect the pitch or loudness of the sound, but does determine its *timbre* or quality.

Sonorous tubes are called mouth pipes or reed pipes, according to the way in which the column of air is made to vibrate.

467. Stopped Pipes.—A sonorous tube may have one end stopped or both ends open. In either case, the tones are due to waves of condensation and rarefaction transmitted through the length of the tube. In a stopped pipe, the air particles at the closed end have no opportunity for vibration; this end of the tube is, therefore, a node. The mouth of the tube affords opportunity for the greatest amplitude. The length of such a pipe is one-fourth the wave length of its fundamental tone.

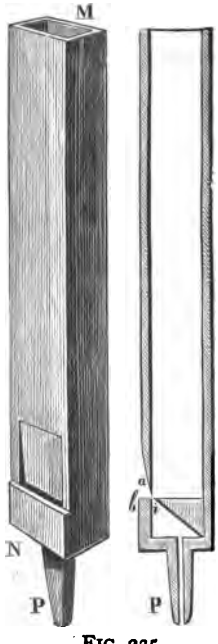


FIG. 235.

468. Open Pipes.—In an open pipe, the ends afford opportunity for the greatest amplitude; the node will fall at the middle. The air column will now equal one-half the wave length; the tone will be an octave higher than that produced by a stopped pipe of the same length.

469. Organ Pipes.—The organ pipe affords the best illustration of mouth pipes. Fig. 235 represents the most common kind of organ pipe, which may be of wood or metal, rectangular or cylindrical. The air current from the bellows enters through *P*, passes into a small chamber, emerges through the narrow slit *i*, and escapes in puffs between *a* and *b*, the two lips

of the mouth. The puffs are due to the fact that the air current from *i* strikes upon the bevelled lip *a* and breaks into a flutter. The puffing sound thus produced consists of a confused mixture of many faint sounds. The air column of the pipe can resound to only one of these tones. The resonance of the air column brought about in this way constitutes the tone of the pipe.

(*a.*) We see, from the above, that it makes little difference how the pulses of air are produced. A vibrating tuning-fork held at the mouth of a pipe of the same pitch is enough to make the pipe sound forth its tone. The production of the tone is strictly analogous to the phenomena mentioned in § 450.

470. Reed Pipes.—A simple reed pipe may be made by cutting a piece of wheat straw eight inches (20 *cm.*) long so as to have a knot at one end. At *r*, about an inch from the knot, cut inward about a quarter of the straw's diameter; turn the knife-blade flat and draw it toward the knot. The strip *rr'* thus raised is a reed; the straw itself is a reed pipe. When the reed is placed in the mouth, the lips firmly closed around the straw between

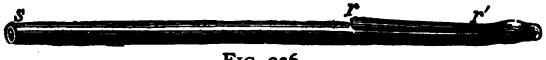


FIG. 236.

r and *s* and the breath driven through the apparatus, the reed vibrates and thus produces vibrations in the air column of the wheaten pipe. Notice the pitch of the musical sound thus produced. Cut off two inches from the end of the pipe at *s*. Blow through the pipe as before and notice that the pitch is raised. Cut off, now, two inches more, and upon sounding the pipe the pitch will be found to be still higher. We thus see that the pipe and not the reed determines the pitch. In each of these three cases

we had the same reed which was obliged to adapt itself to the different vibrations of the different air columns.

(*a.*) It will be easily seen how reeds may be used in musical instruments. The accordeon, clarionet and vocal apparatus are reed instruments.

471. Effect of Lateral Openings.—Certain wind instruments, like the flute, fife and clarionet, have holes in the sides of the tube. On opening one of these holes, opportunity is given for greatest amplitude at that point. This changes the distribution of nodes, affects the length of the segments of the vibrating air columns, and thus determines the wave length or pitch of the tone.

EXERCISES.

1. If a musical sound be due to 144 vibrations, to how many vibrations will its 3d, 5th, and octave, respectively, be due?

2. Determine the length of a tube open at both ends that can resound the tone of a tuning-fork vibrating 512 times a second.

3. A certain string vibrates 100 times a second. (*a.*) Find the number of vibrations of a similar string, twice as long, stretched by the same weight. (*b.*) Of one half as long.

4. A certain string vibrates 100 times per second. Find the number of vibrations of another string that is twice as long, and weighs four times as much per foot and is stretched by the same weight.

5. A musical string vibrates 200 times a second. State (*a.*) what takes place when the string is lengthened or shortened with no change of tension, and (*b.*) what change takes place when the tension is made more or less, the length remaining the same.

6. A tube open at both ends is to produce a tone corresponding (*a.*) to 32 vibrations per second. Taking the velocity of sound as 1120 ft., find the length of the tube. (*b.*) If the number of vibrations be 4480, find the length of the tube.

7. (*a.*) Find the length of an organ pipe whose waves are four feet long, the pipe being open at both ends. (*b.*) Find the length, the pipe being closed at one end.

8. A tuning-fork produces a strong resonance when held over a jar 15 inches long. (*a.*) Find the wave length of the fork. (*b.*) Find the wave period.

9. If two tuning-forks vibrating respectively 256 and 259 times per second be simultaneously sounded near each other, what phenomena would follow?

10. A musical string, known to vibrate 400 times a second, gives a certain tone. A second string sounded a moment later seems to give the same tone. When sounded together, two beats per second are noticeable. (*a.*) Are the strings in unison? (*b.*) If not, what is the rate of vibration of the second string?

11. If a tone be produced by 256 vibrations per second, what numbers will correspond to its third, fifth and octave respectively?

12. If a tone be produced by 264 vibrations per second, what number will represent the vibrations of the tone a fifth above its octave?

Recapitulation.—In this section we have considered Sympathetic Vibrations and Sounding Boards; the Telephone and Phonograph; Reinforcement and Resonance; Interference and Beats; Vibrations of Strings; the Musical Scale; Absolute Pitch; Fundamental Tones; Overtones; the Quality of Sounds; Musical Instruments.

Review Questions and Exercises.

1. (*a.*) Define sound; (*b.*) give its cause; (*c.*) mode of propagation and (*d.*) velocity.

2. (*a.*) Give the rate at which sound is transmitted in air. (*b.*) How is it affected by temperature? (*c.*) Give the law of Reflection. (*d.*) How may it be illustrated?

3. (*a.*) What is capillary attraction? (*b.*) Give three illustrations of the importance of capillary action in the operations of nature.

4. (*a.*) Describe an experiment showing the expansibility of the air. (*b.*) Give the laws of the Pendulum.

5. (*a.*) On what does the loudness of sound depend? (*b.*) How may the pitch of strings be varied? (*c.*) Give the relative number of vibrations in the major diatonic scale, and (*d.*) find the number of vibrations for A_2.

6. (*a.*) Represent by a diagram, a lever of the first class, in which one pound will balance five. (*b.*) Give the laws of falling bodies.

7. Explain the Artesian well by a diagram.

8. (*a.*) What will be the momentum of a ball weighing two ounces after falling $4\frac{1}{2}$ seconds? (*b.*) A stone weighing 20 lbs. on the surface of the earth, would weigh how much at an elevation of 2000 miles from the surface?

9. Define (*a.*) wave length; (*b.*) wave period; (*c.*) amplitude of vibration; (*d.*) phase of a vibrating particle.

10. (*a.*) What would be the effect of making a small hole at the highest point of a siphon in action? (*b.*) What effect upon the action of a siphon would be produced by carrying it up a mountain? (*c.*) What effect would follow if the atmosphere were suddenly to become denser than the liquid being moved?

11. Describe (*a.*) a complete sound wave and (*b.*) its manner of propagation. (*c.*) How does the transmission of sound through a smooth tube differ from its transmission through the open air?

12. Give the laws for pressure of liquids and explain each by some fact or experiment.

13. (*a.*) Distinguish clearly between noise and music. (*b.*) What is meant by timbre? (*c.*) By pitch?

14. (*a.*) Give three examples of musical sounds that agree in one and differ in two elements or characteristics, making a different element agree each time.

15. Give three examples of musical sounds that differ in one and agree in two elements, making a different element differ each time.

16. (*a.*) What are sympathetic vibrations? (*b.*) How may they be produced? (*c.*) What are beats? (*d.*) How may they be produced?

17. (*a.*) What is Archimedes' Principle? (*b.*) How is it applied in finding the specific gravity of a solid?

18. How much water per hour will be delivered from an orifice of 2 inches area 49 feet below the surface of a tank kept full?

19. Describe the telephone.

20. (*a.*) Describe the electrophorus. (*b.*) Explain its action.

21. (*a.*) Describe an organ pipe. (*b.*) Make a reed pipe.

22. (*a.*) Explain the charging of the Leyden jar; (*b.*) when charged what is the electric condition of the outside and inside of the jar?

23. (*a.*) A body falls for six seconds; find the distance traversed in the last two seconds of its fall. (*b.*) How far will a body fall in $\frac{1}{10}$ of a second beginning at the end of four seconds? (*c.*) Explain the "kick" of a gun.

24. (*a.*) Show that if, in an Attwood's machine, one weight be $\frac{3}{5}$ as heavy as the other, its increment of velocity will be $\frac{1}{4}$ that of a freely falling body. (*b.*) That if the lighter weight be $\frac{4}{7}$ of the heavier, its increment of velocity will be $\frac{1}{8}\,g$.

CHAPTER VIII.

HEAT.

SECTION I.

TEMPERATURE, THERMOMETERS, EXPANSION.

472. Introductory Quotation.—"There are other forces besides gravity, and one of the most active of these is chemical affinity. Thus, for instance, an atom of oxygen has a very strong attraction for one of carbon, and we may compare these two atoms to the earth and a stone lodged upon the top of a house. Within certain limits, this attraction is intensly powerful, so that when an atom of carbon and one of oxygen have been separated from each other, we have a species of energy of position just as truly as when a stone has been separated from the earth. Thus by having a large quantity of oxygen and a large quantity of carbon in separate states, we are in possession of a large store of *energy* of position. When we allowed the stone and the earth to rush together, the *energy* of position was transformed into that of actual motion (§ 159), and we should therefore expect something similar to happen when the separated carbon and oxygen are allowed to rush together. This takes place when we burn coal in our fires, and the primary result, as far as *energy* is concerned, is the production of a large amount of heat. We are, therefore, led to conjecture that heat may denote a motion of particles on the small scale just as the rushing together of the stone and the earth denotes a motion on the large. It thus appears that we may have invisible molecular *energy* as well as visible mechanical *energy*."—*Balfour Stewart.*

473. What is Heat?—*Heat is a form of energy. It consists of vibratory motions of the molecules of matter or results from such motions, and*

gives rise to the well known sensations of warmth and cold. By means of these effects upon the animal body it is generally recognized. Being a form of energy, it is a measurable quantity but not a material substance.

474. What is Temperature?—*The temperature of a body is its state considered with reference to its ability to communicate heat to other bodies.* It is a term used to indicate how hot or cold a body is. When a body receives heat its temperature generally rises, but sometimes a change of condition (§ 53) results instead. When a body gives up heat, its temperature falls or its physical condition changes.

475. An Unsafe Standard.—When we put a very warm hand into water at the ordinary temperature, we say that the water is cold. If another person should put a very cold hand into the same water he would say that the water is warm. If a person place one hand in water freezing cold and the other hand in water as hot as he can endure, and, after holding them there some time, plunge them simultaneously into water at the ordinary temperature, the hand from the cold water feels warm while the hand from the hot water feels cold. These experiments show that bodily sensations cannot be trusted to measure this form of energy that we call heat.

476. Thermometers. — *An instrument for measuring temperature is called a thermometer.* The mercury thermometer is the most common. Its action depends upon the facts that heat expands mercury more than it does glass, and that when two bodies of different temperatures are brought into contact, the warmer one will give heat to the colder one until they have a common temperature.

477. Graduation of Thermometers.—Thermometers are graduated in different ways, but in all cases there are two fixed points, viz., the freezing and the boiling

points of water; or, more accurately, the temperature of melting ice and the temperature of steam as it escapes from water boiling under a pressure of one atmosphere.

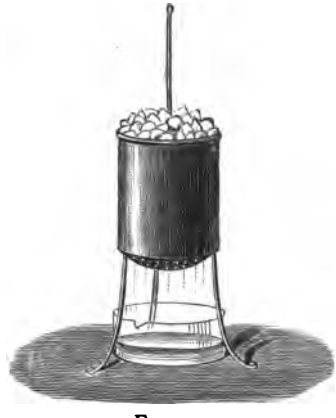


FIG. 237.

478. Determination of the Freezing Point.—Ice in contact with water cannot be raised above a certain temperature; water in contact with ice cannot be reduced below the same temperature. Here, then, is a temperature fixed and easily produced. The thermometer is placed in melting ice or snow contained in a perforated vessel. When the mercury column has come to rest, a mark is made on the glass tube at the level of the mercury. This point is, for the sake of brevity, called the freezing point.

479. Determination of the Boiling Point.—The temperature of steam issuing from water boiling under any given pressure is invariable. Fig. 238 represents a metal vessel in which water is made to boil briskly. The thermometer being supported as represented is surrounded by the steam but does not touch the water. That the steam may not cool before it comes into contact with the thermometer, the sides of the vessel are surrounded by what is called a "steam-jacket." A bent tube open at both ends and containing mercury in the bend is sometimes added. When the mercury stands at the same level in both arms, the pressure upon the surface of the boiling liquid is just equal to the external atmospheric pressure, which should be 760 *mm.* When the mercury column has come to rest, a mark is made on the glass tube at the level of the mercury. This point is, for the sake of brevity, called the boiling point.

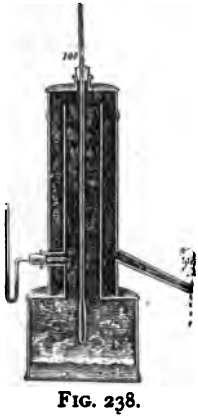


FIG. 238.

480. Thermometric Scales.—There are two scales used in this country, the centigrade and Fahrenheit's. For these scales, the fixed points, determined as just explained, are marked as follows:

FIG. 239.

	Centigrade.	*Fahrenheit.*
Freezing point,	0°	32°
Boiling point,	100°	212°

The tube between these two points is divided into 100 equal parts for the centigrade scale and into 180 for Fahrenheit's. Hence a change of temperature of 5° C. is equal to a change of 9° F., or an interval of one centigrade degree is equal to an interval of $\frac{9}{5}$ of a Fahrenheit degree.

481. Thermometric Readings.—To change the readings of a centigrade thermometer to those of Fahrenheit's, or *vice versa*, is a little more complicated than to determine the relation between the intervals of temperature. This complication arises from the fact that Fahrenheit's *zero* is not at the freezing point but 32 degrees below. To reduce Fahrenheit readings to centigrade readings, subtract 32 from the number of Fahrenheit degrees and multiply the remainder by $\frac{5}{9}$.

$$C. = \frac{5}{9}(F. - 32).$$

To reduce centigrade readings to Fahrenheit readings, multiply the number of centigrade degrees by $\frac{9}{5}$ and add 32.

$$F. = \frac{9}{5}C. + 32.$$

(*a.*) Suppose that we desire to find the equivalent centigrade reading for 50° F. Subtracting 32, we see that this temperature is 18 Fahrenheit degrees above the freezing point. But one Fahrenheit degree being equal to $\frac{5}{9}$ of a centigrade degree, this temperature

is $\frac{5}{9}$ of 18, or 10 centigrade degrees above the freezing point. Hence the reading will be 10° C.

(*b.*) Suppose that we desire to find the equivalent Fahrenheit reading for 45° C. This temperature is 45 centigrade degrees above the freezing point, or 81 Fahrenheit degrees above the freezing point. Hence the reading will be (81 + 32 =) 113° F. (See Fig. 239.)

(*c.*) The centigrade thermometer is the most convenient and is adopted in all countries as the standard scale for scientific reference. Like the metric system, its general use in this country is probably only a question of time.

Note.—It is desirable that this class be provided with several "chemical" thermometers; *i. e.*, thermometers having the scale marked on the glass tube instead of a metal frame.

482. Differential Thermometer.—Leslie's differential thermometer (Fig. 240) shows the difference in temperature of two neighboring places by the expansion of air in one of two bulbs. These bulbs are connected by a bent glass tube containing some liquid not easily volatile. It is an instrument of simple construction (See Appendix, *m.*) and great delicacy of action, but has been largely superseded by the thermopile and galvanometer (§§ 414, 391).

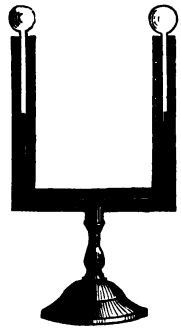


FIG. 240.

483. Expansion.—Heat consists generally of molecular vibrations. Whatever raises the temperature of a body increases the energy with which the molecules of that body swing to and fro. These molecules are too small (§ 5), and their range of motion too minute to be visible, and we must call upon our imaginations to make good the defect of our senses. We must conceive these invisible molecules as held together by the force of cohesion, yet vibrating to and fro. The more intense the heat, the greater the

energy of these molecular motions. Molecules thus vibrating must push each other further apart, and thus cause the body which they constitute *to expand*. This expansion, or increase of volume, is the first effect of heat upon bodies.

(*a.*) Imagine, if possible, twenty-five quiet boys standing closely crowded together. Upon the floor draw a chalk line enclosing the group. If these boys be suddenly set shaking, as by the ague, they will force some of their number over the chalk line. From the motions of the individuals has resulted an expansion of the living mass.

484. Expansion Illustrated.—The expansion of solids may be shown by a ball, which, at ordinary temperatures, will easily pass through a ring; on heating the ball it will no longer pass through the ring. If the ball be cooled by plunging it into cold water, it will again pass through the ring. This illustrates the increase of volume or cubical expansion. Sometimes the expansion in length only is measured. This is called linear expansion. Expansion is also illustrated in the compensation pendulum (§ 149).

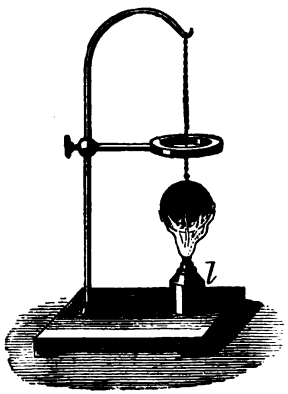


FIG. 241.

485. Unequal Expansion.—Different substances expand at different rates for the same change of temperature. This may be shown by heating a bar made by riveting together, side by side, two thin bars of equal size, one of iron and one of brass, so that the compound bar shall be straight at the ordinary temperature. As brass

expands and contracts more than iron, when the compound bar is heated it will curve with the brass on the convex side; when it is cooled, it will curve with the brass on the concave side.

(*a*.) Glass and platinum expand nearly alike. In fact, the rates of expansion are so nearly alike that platinum wires may be *fused* into glass tubes, as is done in electrolysis apparatus and eudiometers. If we attempt thus to fuse copper wire into glass, the glass will be broken during the unequal contraction from cooling.

486. Practical Applications of Expansion.—The energy of expansion and contraction of solids, when heating and cooling, is remarkable. This expansion of metals by heat is utilized by coopers in setting hoops, by wheelwrights in setting tires, and by builders in straightening bulging walls. When the iron rails of our railways are laid, a small space is left between the ends of each two adjoining rails to provide for their inevitable expansion by the summer heat. The iron tubular bridge over the Menai Straits is about 1800 feet long. Its linear expansion is about one foot, and is provided for by placing the ends of the huge tube upon rollers.

487. Expansion of Liquids.—The expansion of liquids may be illustrated as follows: Nearly fill a Florence flask with water, and place it on a retort stand or other convenient support. A long straw is supported by a thread tied near one end. From the short end of this straw lever is suspended a weight nearly balanced by the long arm of the lever. This weight hangs in the neck of the flask, and rests lightly upon the surface of the water (§ 238). By placing a spirit-lamp below the flask the water may be heated. As it expands, it rises in the neck of the flask, raises the weight, and lowers the end of the long arm of the lever, which may be seen to move.

488. Anomalous Expansion of Water.—Water presents a remarkable exception to the general rule. *If water at* 0°C. *be heated, it will contract until it*

reaches 4° C., its temperature of greatest density. Heated above this point it expands.

(*a.*) Through the cork of a large flask pass a fine glass tube. Fill the flask with water at the ordinary temperature, and insert the cork and tube so that the water shall rise some distance in the tube. Place the flask in a freezing mixture, such as salt and pounded ice. The water column in the tube falls, showing that the water is contracting. But before the water freezes the contraction ceases, the column in the tube becomes stationary, and then begins to rise again. This shows that water does not contract on being cooled below a certain temperature, and that there is a temperature of maximum density above the freezing point.

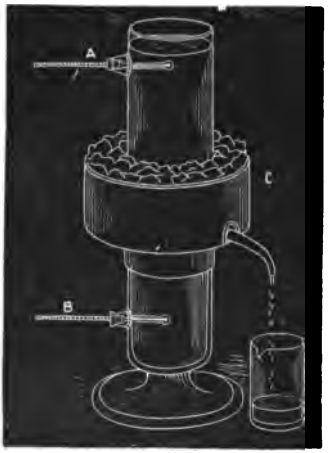


FIG. 242.

(*b.*) Fig. 242 represents a glass cylinder with two thermometers inserted in the side, near the top and bottom, at *A* and *B*. Midway between *A* and *B* is an envelope *C*, which may be filled with a freezing mixture. The envelope being empty, the cylinder is filled with water at 0° C., and placed in a room at the ordinary temperature, about 15° C. As the water molecules at the side of the cylinder become warm, they fall, and *B* soon records a temperature of 4° C., while *A* remains at 0°. This shows that the warm water falls to the bottom. It falls because it is denser. It is denser because it has been *contracted by heat.*

If the experiment be varied by filling the cylinder with water at the ordinary temperature, and *C* with a freezing mixture, the temperature at *B* will fall rapidly, while it falls slowly at *A*. This will continue until *A* reaches 4° C., when *A* begins to fall more rapidly, and continues to do so until it reaches 0°. These experiments show that water is heavier at 4°C. than at any temperature above or below.

489. Results of this Exception.—This property of water is of great importance. Were it otherwise,

the ice would sink and destroy everything living in the water. The entire body of water would soon become a solid mass which the heat of summer could not wholly melt, for, as we shall soon see, water has little power to carry heat downward. As it is, in even the coldest winters, the mass of water in our northern lakes remains at a temperature of 4°C., the colder water floats upon the warmer layer, ice forms over all, and protects the living things below.

490. Expansion of Gases.—The expansion of gases may be shown by partly filling a bladder with cold air, tying up the opening, and placing the bladder near the fire. The expanded air will fill the bladder. Through the cork of a bottle pass a small glass tube about a foot long. Warm the bottle a little between the hands and place a drop of ink at the end of the tube. As the air contracts the ink will move down the tube and form a frictionless liquid index. By heating or cooling the bottle the index may be made to move up or down. If a closed flask having a delivery tube terminating under water be heated, some of the expanded air will be forced to escape, and may be seen bubbling through the water. By "collecting over water" the air thus driven out, it may be accurately measured. (Fig. 243.)

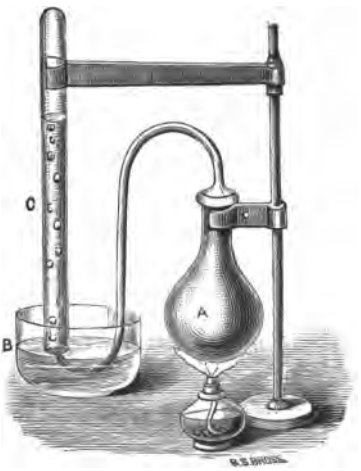


FIG. 243.

491. Practical Results.—The ascension of "fire-balloons" and the draft of chimneys are due to the expansion of gases by heat. When the air in the chimney of a stove or lamp is heated, it is rendered lighter than the same bulk of surrounding air, and, therefore, rises. The cooler air comes in to take its place and thus feeds the combustion. Sometimes when a fire is first lighted, the chimney is so cold that the current is not quickly established and the smoke escapes into the room. But in a little while the air column rises and the usual action takes place. By the aid of a good thermometer it may be shown that the air near the ceiling of a room is warmer than the air near the floor. When the door of a warmed room is left slightly ajar, there will be an inward current near the floor and an outward current near the top of the door. These currents may be shown by holding a lighted candle at these places. Artificial ventilation depends upon the same principles.

492. Rate of Gaseous Expansion.—The rate of expansion is practically the same for all gases, viz., 0.00336 or $\frac{1}{273}$ of the volume at 0° C., for each centigrade degree that the temperature is raised above the freezing point. In other words, a liter of air at 0° C., expands to

1 *l.* + .00336 *l.* at 1° C.,	1 *l.* + (.00336 × 3) *l.* at 3° C.,
1 *l.* + (.00336 × 2) *l.* at 2° C.	$1\frac{4}{273}$ *l.* at 4° C.

Of course, if we use Fahrenheit degrees the expansion will be only $\frac{5}{9}$ as great, or about $\frac{1}{490}$. A litre of gas at 32° F. expands to $1\frac{1}{490}$ *l.* at 33° F.; to $\frac{491}{490}$ *l.* at 39° F., etc.

493. Absolute Zero of Temperature.—*The temperature at which the molecular motions constituting heat wholly cease is called the absolute zero.* It has never been reached, and has been only approximately determined, but it is convenient as an ideal starting-point. The zero point of the thermometers does not indicate the total absence of heat. A Fahrenheit thermometer, therefore, does not indicate that boiling water is 212 times as hot as ice at 1° F.; a centigrade

thermometer does not indicate that boiling water has 100 times as much heat as water at 1° C.

(*a.*) Temperature, when reckoned from the absolute zero, is called absolute temperature. Absolute temperatures are obtained by adding 460 to the reading of a Fahrenheit thermometer, or 273 to the reading of a centigrade thermometer.

494. Temperature, Volume and Pressure.—By raising a gas from 0° C. to 273° C., its volume will be doubled. To reduce the gas at this temperature to its original volume, the original pressure must be doubled. From our knowledge of Pneumatics and gaseous expansion, we are able to solve certain problems relating to the volume of gases under different pressures and temperatures.

Examples.—(1.) A mass of air at 0° C. and under an atmospheric pressure of 30 inches, measures 100 cu. inches; what will be its volume at 40° C. under a pressure of 28 inches? First, suppose the pressure to change from 30 inches to 28 inches. The air will expand, the two volumes being in the ratio of 28 to 30 (§ 284). In other words, the volume will be $\frac{30}{28}$ times 100 cubic inches or $107\frac{1}{7}$ cu. in. Next, suppose the temperature to change from 0° C. to 40° C. The *expansion* will be $\frac{40}{273}$ of the volume at 0° C.; the *volume* will be $1\frac{40}{273}$ of the volume at 0° C. $1\frac{40}{273}$ times $107\frac{1}{7}$ cubic inches $= 122\frac{114}{911}$ inches.—*Ans.*

The problem may be worked by proportion as follows:

$$\left.\begin{matrix} 28 : 30 \\ 1 : 1\frac{40}{273} \end{matrix}\right\} :: 100 : x. \qquad \text{or} \quad \left.\begin{matrix} 28 : 30 \\ \frac{273}{273} : \frac{313}{273} \end{matrix}\right\} :: 100 : x.$$

$$\text{or} \quad \left.\begin{matrix} 28 : 30 \\ 273 : 273 + 40 \end{matrix}\right\} 100 : x. \qquad \therefore\ x = 122.84 + \text{cu. in.}$$

(2.) At 150° C., what will be the volume of a gas that measures 10 *cu. cm.* at 15° C.?

$$273 + 15 : 273 + 150 :: 10 : x. \qquad \therefore\ x = 14.69\ \textit{cu. cm.}$$

(3.) If 100 *cu. cm.* of hydrogen be measured at 100° C., what will be the volume of the gas at −100° C.?

$$273 + 100 : 273 - 100 :: 100 : x. \qquad \therefore\ x = 46.37\ \textit{cu. cm.}$$

(4.) A liter of air is measured at 0° C. and 760 *mm.* What volume will it occupy at 740 *mm.*, and 15.5° C.?

$$\left.\begin{matrix} 273 : 273 + 15.5 \\ 740 : 760 \end{matrix}\right\} :: 1{,}000 : x. \qquad \therefore x = 1085.34 \text{ cu. cm.}$$

EXERCISES.

1. A rubber balloon, capacity of 1 liter, contains 900 *cu. cm.* of oxygen at 0° C. When heated to 30° C., what will be the volume of the oxygen? *Ans.* 998.9 *cu. cm.*

2. If 170 volumes of carbonic acid gas be measured at 10° C., what will be the volume when the temperature sinks to 0° C.?

3. A certain weight of air measures a liter at 0° C. How much will the air expand on being heated to 100° C.?

4. A gas has its temperature raised from 15° C. to 50° C. At the latter temperature it measures 15 liters. What was its original volume?

5. A gas measures 98 *cu. in.* at 185° F. What will it measure at 10° C. under the same pressure?

6. To what volume will a liter of gas contract in cooling from 42° F. to 32° F.? *Ans.* 980 *cu. cm.*

7. A certain quantity of gas measures 155 *cu. cm.* at 10° C., and under a barometric pressure of 530 *mm.* What will be the volume at 18.7° C., and under a barometric pressure of 590 *mm.*?

8. A gallon of air (231 *cu. in.*) is heated, under constant pressure, from 0° C. to 60° C. What was the volume of the air at the latter temperature?

9. A fire balloon contains 20 *cu. ft.* of air. The temperature of the atmosphere being 15° C., and that of the heated air in the balloon being 75° C., what weight, including the balloon, may be thus supported? (See Appendix, *g.*)

10. The difference between the temperatures of two bodies is 36° F. Express the difference in centigrade degrees.

11. The difference between the temperatures of two bodies is 35° C. Express the difference in Fahrenheit degrees.

12. (*a.*) Express the temperature 68° F. in the centigrade scale. (*b.*) Express the temperature 20° C. in the Fahrenheit scale.

13. What will be the tension at 30° C. of a quantity of gas which at 0° C. has a tension of a million dynes per *sq. cm.*, the volume remaining the same? (§ 69.) *Ans.* 1109800 dynes.

14. A liter of gas under a pressure of 1013600 dynes per *sq. cm.* is allowed to expand until the pressure is reduced to 1000000 dynes per *sq. cm.* At the same time, the temperature is raised from 0° C to 100° C. Find the final volume. *Ans.* 1385 *cu. cm.* nearly.

Recapitulation.—In this section we have considered the Nature of Heat; the meaning of Temperature; Thermometers and their graduation; the determination of the Freezing and Boiling Points; thermometric Scales and Readings; the Differential Thermometer; Expansion of Solids; Expansion of Liquids, especially the Expansion of Water; the Expansion of Gases and the Rate thereof; Absolute Zero of temperature; the relation between Temperature, Pressure and Volume.

SECTION II.

LIQUEFACTION, VAPORIZATION, DISTILLATION.

495. Liquefaction.—In the last section we learned that heat is a form of energy. As energy, it is able to perform work, such as overcoming or weakening the force of cohesion. It is well known that when a solid is changed to the liquid or aëriform condition, or when a liquid is changed to a vapor, it is done by an increase of heat, and that when the reverse operations are performed, it is by a diminution of heat. Cohesion draws the particles together; heat pushes them asunder, and on the varying preponderance of one or the other of these antagonistic powers, the condition of the body seems to depend. When the firm grip of cohesion has been so far weakened by heat that the molecules easily change their relative positions (§ 55), the body passes from the solid into the liquid condition. This change of condition is called liquefaction.

496. Laws of Fusion.—It has been found by experiment that the following statements are true:

(1.) Every solid begins to melt at a certain temperature which is invariable for the given substance if the pressure be constant. When cooling, the substance will solidify at the temperature of fusion.

(2.) The temperature of the solid, or liquid, remains at the melting point from the moment that fusion or solidification begins until it is complete.

(*a.*) If a flask containing ice be placed over a fire, it will be found that the hotter the fire the more rapid the liquefaction, but that if the contents of the flask be continually stirred, the thermometer will remain at 0° C. until the last bit of ice is melted (§ 478). If sulphur be used instead of ice, the temperature will remain at 115° C. until the sulphur is all melted. (Fig. 244.)

FIG. 244.

497. Reference Table of Melting Points:

Alcohol,	Never frozen.
Mercury,	—38.8°C.
Sulphuric acid,	—34.4
Ice,	0.
Sulphur,	115.
Lead,	326
Zinc,	425
Silver (pure),	1,000
Gold (pure),	1,250
Iron (wrought),	1,600

Note.—The higher temperatures in this table are only approximate. Certain bodies soften and become plastic before they melt. In this condition glass is worked and iron is welded.

498. Vaporization.—If, after liquefaction, further additions of heat be made, a point will be reached at which the heat will overbalance both the cohesion and the pressure of the atmosphere and the liquid pass into the aëriform condition. This change of form is called vapor-

ization. Vaporization may be of two kinds—evaporation and ebullition.

499. Evaporation.—*Evaporation signifies the quiet formation of vapor at the surface of a liquid.*

(*a.*) With reference to the rapidity with which evaporation takes place, it may be remarked that—

(1.) It varies with the temperature.
(2.) It varies with the extent of surface.
(3.) It varies with pressure upon the liquid, being exceedingly rapid in a vacuum.

500. Evaporation in Vacuo.—The rapid formation of vapors in a vacuum is prettily illustrated by the following experiment: Torricellian vacua are formed at the top of four barometer tubes, *A*, *B*, *C* and *D*, Fig. 245. Into the mouth of *B* pass a few drops of water. They will rise through the mercury to the vacuum at the top. Upon reaching this open space they are *instantly vaporized.* The tension of the aqueous vapor shows itself by lowering the mercury column. This depression is due to the tension rather than to the weight of the vapor, because the water weighs scarcely anything compared with the mer-

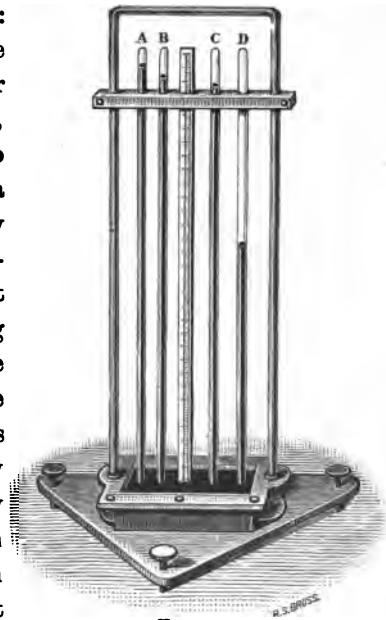


FIG. 245.

cury it displaces. Introducing the same quantity of alcohol into *C*, and of ether into *D*, they are instantly vaporized, but the mercury will be depressed more by the alcohol than by the water, and more by the ether than by the alcohol.

(*a*.) At the beginning of the experiment, the four mercury columns indicated the atmospheric pressure; at the end of the experiment, the column in *A* indicated the full pressure of the atmosphere; the columns in *B*, *C* and *D* indicate that pressure *minus* the tension of their respective vapors. This experiment also shows that, *at the same temperature, the vapors of different liquids have different tensions.*

501. Ebullition.—*Ebullition, or boiling, signifies the rapid formation of vapor bubbles in the mass of a liquid.* When a flask containing water is placed over the flame of a lamp, the absorbed air that is generally to be found in water is driven off in minute bubbles that rise and escape without noise. As the temperature of the water is raised, the liquid molecules in contact with the bottom of the flask become so hot that the heat is able to overcome the cohesion between the molecules, the pressure

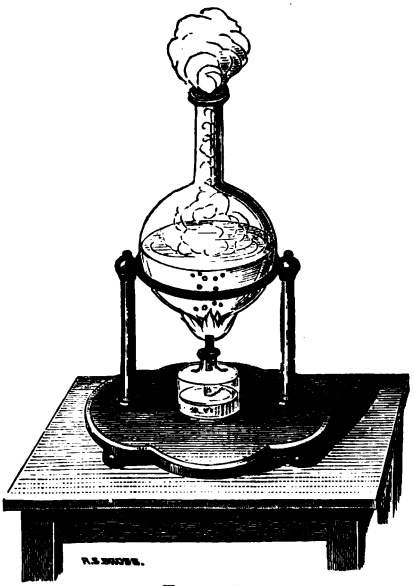


FIG. 246.

of the overlying water, and the pressure of the atmosphere above the water. Then the water boils.

(*a.*) When the first bubbles of steam are formed at the bottom of the water, they rise through the water, condense in the cooler layers above, and disappear before reaching the surface. The formation and condensation of these bubbles produce the peculiar sound known as *singing* or *simmering*, the well-known herald of ebullition. Finally, the water becomes heated throughout, the bubbles increase in number, grow larger as they ascend, burst at the surface, and disappear in the atmosphere. The whole liquid mass is agitated with considerable vehemence, there is a characteristic noisy accompaniment, the quantity of water in the flask diminishes with every bubble, and finally it all disappears as steam. The water has "boiled away."

502. Laws of Ebullition.—It has been found by experiment that the following statements are true:

(1.) Every liquid begins to boil at a certain temperature, which is invariable for the given substance if the pressure be constant. When cooling, the substance will liquefy at the temperature of ebullition, or at the boiling point.

(2.) The temperature of the liquid, or vapor, remains at the boiling point from the moment that it begins to boil or liquefy.

(3.) An increase of pressure raises the boiling point; a decrease of pressure lowers the boiling point.

503. Effect of Pressure upon Boiling Point. We saw in § 501 that when a liquid is boiled, the heat has three tasks or three kinds of work to perform, viz., overcoming cohesion, liquid and atmospheric pressures. Nothing can be more evident than the propositions that increasing the work to be done involves an increase in the energy needed to do the work; that decreasing the work to be done involves a decrease in the energy needed to do the work. In the case of boiling any given liquid, the first

of the three tasks can not be varied; either of the other two easily may. If we increase the pressure we increase the work to be done, and therefore increase the necessary amount of heat, the only form of energy competent to do the work. If we lower the pressure we lessen the work to be done, and therefore lessen the necessary amount of heat. This means, in the first case, raising the boiling point; in the second case, lowering the boiling point.

504. Franklin's Experiment.—The boiling of water at a temperature below 100° C. may be shown as follows: Half fill a Florence flask with water. Boil the water until the steam drives the air from the upper part of the flask. Cork tightly, remove the lamp and invert the flask. The exclusion of the air may be made more certain by immersing the corked neck of the flask in water that has been recently boiled. When the lamp was removed the temperature was not above 100° C. By the time that the flask is inverted and the boiling has ceased the temperature will have fallen below 100° C. When the boiling stops, pour cold water upon the flask; directly the boiling begins again.

FIG. 247.

(*a.*) The cold water poured upon the flask lowers the temperature of the water in the flask still further, but it also condenses some of the steam in the flask or reduces its tension (§ 494). This re-

duction of the tension lessens the work necessary to boiling. There being enough heat in the water to do this lessened amount of work, the water again boils and increases the pressure until the boiling point is raised above the present temperature of the water. The flask may be drenched and the water made to boil a dozen times in succession with a single heating. The experiment may be made more striking by plunging the whole flask under cool water.

505. The Culinary Paradox.—The same principle may be illustrated by the apparatus represented in Fig. 248. The receiver *R*, having been exhausted with an air-pump, is closed by the stop-cock *s*. The flask *F* is half full of water and heated by a lamp placed beneath. As the water boils, the steam escapes through the open stop-cocks *a* and *c*. When the steam has expelled the air from *F*, close *a* and *c*, removing the lamp at the same time. The water gradually cools and ceases to boil. Water may be dashed over *F* and the water made to boil as in the last experiment. When this has been done a few times, the water may be allowed to come to rest. It will be several degrees below the boiling point. Opening *a* and *s*, the vapor of *F* escapes into *R* and the water begins to boil vigorously. By keeping *R* cool, the water in *F* may be made to boil for a considerable time.

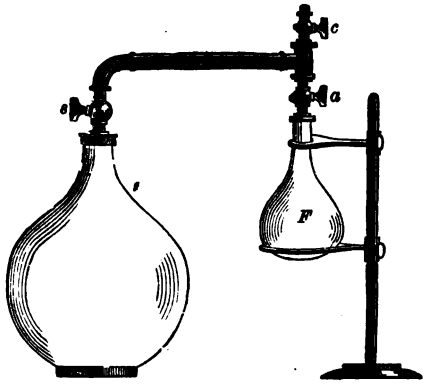


FIG. 248.

506. Papin's Digester.—At high elevations water boils at a temperature too low for culinary purposes. Persons living there

are obliged to boil meats and vegetables (if at all) in closed vessels and under a pressure greater than that of the atmosphere. In the arts, a higher temperature than 100° C. is sometimes required for water, as, for example, in the extraction of gelatine from bones. In a closed vessel, water may be raised to a much higher temperature than in the open air, but, for reasons now obvious, water cannot be kept boiling in such a vessel. Papin's Digester consists of a metal vessel of great strength covered with a lid pressed down by a powerful screw. That the joint may be more perfect, a ring of sheet lead is placed between the edges of the cover and of the vessel. It is provided with a safety valve, pressed close by a loaded lever. When the tension of the steam reaches a dangerous point, it opens the valve, lifting the weight, and thus allows some of the steam to escape.

507. Marcet's Globe.—Marcet's globe is represented in Fig. 249. It consists of a spherical metallic boiler, five or six inches in diameter, provided with three openings, through one of which a thermometer, *T*, passes; through the second of which a glass manometer tube, *M*, passes; the third opening being provided with a stop-cock, *S*. The thermometer and manometer tubes fit their openings so closely that no steam can escape at those points. The thermometer bulb is exposed directly to the steam. The lower end of the manometer tube dips into mercury placed in the lower part of the globe. The boiler is to be half filled with water and heated until the water boils, the stop-cock being open. As long as the stop-cock is open, the thermometer will not rise above 100° C. When the stop-cock is closed, the steam accumulates, the pressure on the water increases, the thermometer shows a rise of temperature beyond 100° C. higher and higher as the mercury rises in the manometer tube,

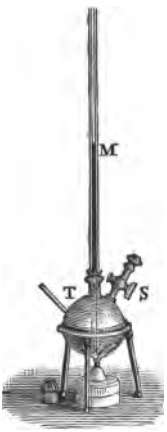


FIG. 249.

When the mercury in the manometer tube is 760 *mm.* above the level of the mercury in the boiler, the steam has a tension of two atmospheres, and the thermometer will record a temperature of about 121° C.

508. Concerning Steam.—*A given mass of water in the aeriform condition occupies nearly 1700 times as much space under a pressure of one atmosphere as it does in the liquid condition.* In other words, a cubic inch of water will yield nearly a cubic foot of steam. *Steam is invisible.* What is commonly called steam is not true steam, but little globules of water condensed by the cold air and suspended in it. By carefully noticing the steam issuing from the spout of a tea-kettle, it will be observed that for about an inch from the spout there is nothing visible. The steam there has not had opportunity for condensation. The water particles visible beyond this space passed through it as invisible steam. The steam in the flask of Fig. 247 and in *F* of Fig. 248 is invisible

509. Reference Tables.—Boiling Points under a pressure of one atmosphere:

Ammonia	−40° C.	Alcohol	78° C.
Sulphurous anhydride	− 8	Water (pure)	100
Ether	35	Mercury	350
Carbon bisulphide	48	Sulphur	447

Some solids, as iodine, arsenic and camphor vaporize without visible intermediate liquefaction. The process is called *sublimation.*

Boiling Points of water at different pressures:

Thermometer.	*Barometer.*	*Thermometer.*	*Atmospheres.*
184° F.	16.676 inches.	212° F.	1
190	18.992	249.5	2
200	23.454	273.3	3
210	28.744	318.2	6
212	29.922	356.6	10
215	31,730	415.4	20

510. Definition of Boiling Point.—We ought now to be fully prepared to understand that *the boiling point of a liquid is the temperature at which it gives off a vapor of the same tension as the surrounding atmosphere.*

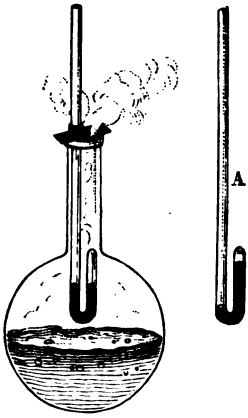


FIG. 250.

(*a.*) If there be any doubt or lack of comprehension of this proposition, it may be removed by the following experiment: A glass tube, bent as shown at *A*, has its short arm closed and its long arm open. The short arm is nearly filled with mercury, the space above the mercury being filled with water. While water is briskly boiling in a flask, the bent tube is suspended in the steam, as shown in Fig. 250. Part of the water in the bent tube is changed to vapor, the mercury falls in the short arm, and finally *assumes the same level in both branches.*

511. Distillation.—Distillation is a process of separating a liquid from a solid which it holds in solution, or of separating a mixture of two liquids having different boiling points. The process depends upon the fact that different substances are vaporized at different temperatures. The apparatus, called a still, is made in many forms, but consists essentially of two parts—the retort for producing vaporization, and a condenser for changing the vapor back to the liquid form. Fig. 251 represents one form of the apparatus. It consists of a retort, *ab*, the neck of which is connected with a spiral tube, *dd*, called *the worm.* The worm is placed in a vessel containing water. This vessel is continually fed with cold water carried to the bottom by the tube *h.* As the water is warmed by the worm it rises and overflows at *i.*

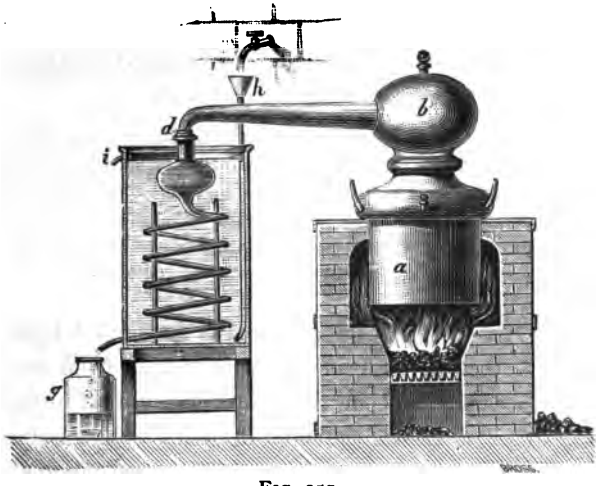


FIG. 251.

512. Distillation of a Liquid from a Solid.—Suppose that water is to be separated from the salt it holds in solution. The brine is placed in a retort and heated a little above 212° F. At this temperature the water is vaporized while the salt is not. The steam is driven from the retort through the worm, where it is rapidly condensed and passes into a vessel prepared to receive it. The salt remains in the retort. Of course, the water of the vessel containing the worm

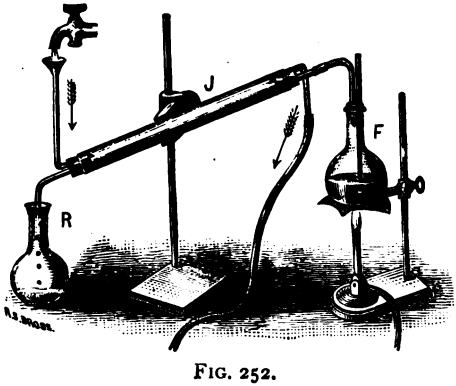


FIG. 252.

must be kept cool. This is done by constantly feeding it at the bottom with cold water, as explained in the last article.

(*a.*) Fig. 252 represents a simpler form of apparatus for this purpose. The retort is a Florence flask, the delivery tube of which passes through a "water-jacket." The method of supplying this condenser with cold water is evident from the figure. Sometimes the delivery tube passes directly into a vessel placed in a cold water bath, this vessel serving as both condenser and receiver.

513. Distillation of a Liquid from a Liquid.—Suppose that alcohol is to be separated from water. The solution is placed in the retort and heated to about 90° C., which is above the boiling point of alcohol but below that of water. The alcohol will pass over in a state of vapor and be condensed, while the water, etc., remains behind. In practice, the alcohol vapor passes over charged with a certain amount of steam. A receiver placed in a bath containing boiling water is interposed between the retort and the *worm* or condenser. In this receiver the steam condenses, while the vapor of alcohol passes on to the worm where it also is condensed. This process is known as "fractional distillation."

Recapitulation.—In this section we have considered the meaning of Liquefaction; the Laws of Fusion; the meaning and kinds of Vaporization; Evaporation in air and in vacuo; Ebullition and its Laws; effect of Pressure upon the boiling point; Steam; definition of Boiling Point; Distillation.

SECTION III.

LATENT AND SPECIFIC HEAT.

514. Thermal Units.—In § 473 it was stated that heat is measurable; but that we may measure it, a standard or unit of measure is necessary. *A thermal or heat unit is the amount of heat necessary to warm a weight unit of water one degree above the freezing point.* The weight unit generally used is the kilogram or pound; any other weight unit may be used with equal propriety. The degree may be centigrade or Fahrenheit.

(*a.*) We therefore have at least four units in common use. They are the amounts of heat necessary to warm

(1.) A kilogram of water from 0° C. to 1° C.
(2.) A kilogram of water from 32° F. to 33° F.
(3.) A pound of water from 0° C. to 1° C.
(4.) A pound of water from 32° F. to 33° F.

It makes no practical difference which unit is used, excepting so far as convenience is concerned, but the unit must not be changed during any problem.

515. Two Fruitful Questions.—We have already seen that heat melts ice, and that during the melting the temperature is constant; that heat boils water, and that during the boiling the temperature is constant. One feature of this change of condition remains to be noticed more fully. Take a block of ice with a temperature of −16° C. (14° F.) and warm it. A thermometer placed in it rises to 0° C. The ice begins to melt, but the mercury no longer rises. Heat is still applied, but there is no increase of temperature; the mercury in the thermometer remains stationary until the last particle of ice has been liquefied. Then, and not till then, does the temperature begin to rise. It continues to do so until the thermometer marks 100° C. The liquid then begins to boil, and the temperature a second time becomes fixed. But during all the time that the thermometer stood at 0° C., or while the ice was melting, heat was given by the lamp and received by the ice. Why then did not the temperature rise during that time, instead of remaining the

same until the last particle of ice was melted? After the water began to boil, heat was continuously supplied. Why then was there not a continued increase of temperature?

516. Molecular Energies.—Heat is a form of energy and may be kinetic or potential. There can be no doubt that when a body is heated its molecules are thrown into violent motion, and that as the temperature is raised the energy of this molecular motion is increased, or that as this molecular motion is increased, the temperature is raised. But some of this molecular energy that we call heat, instead of being used to set the molecules of the body in motion, has work of a different kind to perform. That part of the heat which is spent in producing molecular vibrations, which increases the temperature, is called *sensible heat*. Another part is employed in pushing the molecules of the body asunder, producing expansion and change of condition. In forcing these molecules asunder, invisible energy of motion is changed to energy of position as truly and as necessarily as visible energy of motion is changed to the potential variety in throwing or carrying a stone from the earth to the house-top. (§ 159.)

517. Transmutation of Molecular Energy.—In most cases, but little of the heat communicated to a body is thus changed to potential energy, the greater part remaining energy of motion and increasing the temperature. But there are certain crises, or "critical occasions," on which the *greater* part of the heat communicated is transformed into energy of position. Thus, at the melting point, a large quantity of heat may be given to ice without affecting the temperature at all; instead of raising the temperature, it merely melts the ice. The energy used has been changed from the kinetic to the potential variety. In like manner, at the boiling point, a large quantity of heat may be given to the water without affecting the temperature at all. Instead of raising the temperature further, it merely vaporizes the water, and the steam has the same temperature as the water from which it came. The same change of molecular energy of motion into molecular energy of position has again taken place. This heat, which is thus used to overcome cohesion and change the condition of matter, does not affect the temperature and therefore is not *sensible*, but is stored up as potential energy and thus hidden or rendered *latent*.

518. Definition of Latent Heat.—*The latent heat of a substance is the quantity of heat that is*

lost to thermometric measurement during its liquefaction or vaporization, or the amount of heat that must be communicated to a body to change its condition without changing its temperature. It may be made to reappear during the opposite changes after any interval of time. Many solids may undergo two changes of condition. Such solids have a latent heat of liquefaction and a latent heat of vaporization.

519. Latent Heat of Fusion.—We are already familiar with the fact that when ice or any other solid is melted by the direct application of heat, much of the heat is rendered latent. In the case of melting ice we shall show how this latent heat is measured, and that its quantity is very great. We may represent the process of liquefaction of ice as follows:

Water at 0° C. = ice at 0° C. + latent heat of water.

520. Latent Heat of Solution.—During the process of solution, as well as during fusion, heat is rendered latent. In either case the performance of the *work* of liquefaction demands an expenditure of kinetic energy. Hence *the solution of a solid involves a diminution of temperature.*

(*a.*) This loss may in some cases be made good by an equal increase, or changed to gain by a greater increase of sensible heat from the chemical changes involved; but in any case, the act of liquefaction considered by itself produces cold. Thus a cup of coffee is cooled by sweetening it with sugar, and a plate of soup is cooled by flavoring it with salt.

521. Freezing Mixtures.—*The latent heat of solution lies at the foundation of the action of freezing mixtures.* For example, when ice is melted by salt, and the water thus formed, in turn, dissolves the

salt itself, the double liquefaction requires a deal of heat which is generally furnished by the cream in the freezer. The freezing mixture most commonly used consists of one weight of salt and two weights of snow or pounded ice. The mixture assumes a temperature of −18° C., which furnished the zero adopted by Fahrenheit.

(*a.*) By mixing, at the freezing temperature, three weights of snow with two weights of dilute sulphuric acid, the temperature may be reduced to about −20° F., a diminution of over 50 Fahrenheit degrees. If equal weights of snow and dilute sulphuric acid be thus reduced to a temperature of −20° F. and then mixed, the temperature will fall to about −60° F. By mixing equal weights of sodium sulphate crystals (Glauber's salt), ammonium nitrate and water, all at the ordinary temperature, and stirring the mixture with a thermometer, the temperature will be seen to fall from about 65° F. to about 10° F., which is considerably below the freezing point of pure water. Glauber's salt and chlorhydric (muriatic) acid form a good freezing mixture.

522. Solidification.—Solidification signifies the passage from the liquid to the solid condition. *During solidification there is an increase of temperature.* This may seem paradoxical in certain cases, but, even in the case of water, it is true that solidification is a warming process.

(*a.*) The sensible heat that disappeared as latent heat during liquefaction, being no longer employed in doing the work of maintaining liquidity, is reconverted into sensible heat and immediately employed in increasing the molecular vibrations. The molecular potential energy is transmuted into molecular kinetic energy. This is frequently illustrated by the precaution taken in winter to place tubs of water in vegetable cellars that the latent heat of the freezing water may be changed into sensible heat and thus protect the vegetables.

523. Temperature of Solidification.—The melting point is the highest temperature at which solidi-

fication can take place, but it is possible to keep substances in the liquid condition at lower temperatures. Water standing perfectly quiet sometimes cools several degrees below the melting point without freezing, but, upon agitation in any perceptible degree, solidification immediately takes place.

(*a.*) Persons who sleep in cold chambers sometimes notice, upon arising, that as soon as they touch a pitcher of water that has been standing in the room over night, the water quickly freezes. If a particle of ice be dropped into the water the same result follows. We may say that, in this condition, liquids have a tendency to freeze which is kept in check only by the difficulty of making a beginning.

524. Heat from Solidification.—(1.) By surrounding, with a freezing mixture, a small glass vessel containing water, and a mercury thermometer, the temperature of the water may be reduced to —10° C. or —12° C. without freezing the water. A slight movement of the thermometer in the water starts the freezing and the temperature quickly rises to 0° C.

(2.) Place a thermometer in a glass vessel containing water at 30° C. and a second thermometer in a large bath of mercury at —10° C. Immerse the glass vessel in the mercury. The temperature of the water will gradually fall to 0° C., when the water will begin to freeze and its temperature become constant. In the meantime the temperature of the mercury bath rises, and *continues to do so while the water is freezing.*

(3.) Dissolve two weights of Glauber's salt in one weight of hot water, cover the solution with a thin layer of oil and allow to cool, in perfect quiet, to the temperature of the room. By plunging a thermometer into the still liquid substance, solidification (crystallization) is started and the temperature rapidly rises. Dr. Arnott found that this experiment was successful after keeping the solution in the liquid condition for five years.

(4.) Mix equal quantities of dilute sulphuric acid and of a saturated solution of calcium chloride (not chloride of lime), the two liquids having been allowed time to acquire the temperature of the room. The two liquids are converted into solid calcium sulphate, with a marked increase of temperature. In this case, as in some of the other cases, part of the heat observed is probably due to chemical action, but more to the conversion of the latent heat of the liquids.

(5.) To three weights of quicklime add one weight of water. The water will be completely solidified in the slaking of the lime with remarkable thermal manifestations. Carts containing quicklime have been set on fire by exposure to heavy rains.

525. Change of Bulk during Solidification.—Most substances shrink in size during solidification; but a few, such as ice, cast-iron, antimony and bismuth, are exceptions. When melted cast-iron is poured into a mould, it expands in cooling and presses into every part of the mould. The tracings on the casting are, therefore, as clear cut as they were in the mould. A clear-cut casting can not be obtained from lead; this is one of the reasons why antimony is made a constituent of type-metal. Gold coins have to be stamped; they cannot be cast so as to produce a clear-cut design. The bursting of pipes by freezing water is a common source of annoyance.

(*a*.) An army officer at Quebec performed the following experiment: He filled a 12-inch shell with water and closed the opening with a wooden plug forcibly driven in. The shell was put out of doors; the temperature being —28° C., the water froze, the plug was thrown about 300 feet, and a tongue of ice about eight inches long protruded from the opening. In a similar experiment, the shell split and a rim of ice issued from the rent.

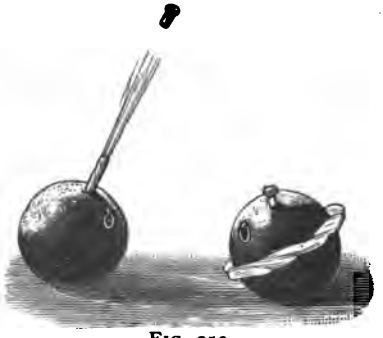


FIG. 253.

526. Latent Heat of Vaporization.—The vaporization of a liquid is accompanied by the disappearance of a large quantity of heat, and frequently by a diminution of temperature. There is a change of sensible into

latent heat; of kinetic into potential energy. We may represent, for instance, the vaporization of water as follows:

Steam at 100° C. = water at 100° C. + latent heat of steam.

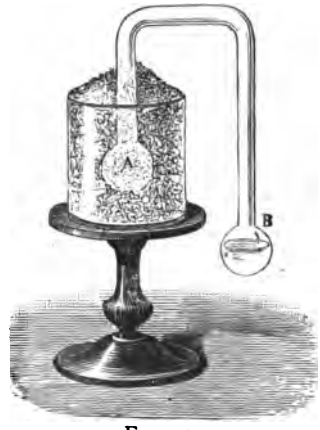


FIG. 254.

(*a.*) The cryophorus, shown in Fig. 254, consists of a bent tube and two bulbs containing a small quantity of water. The air is removed by briskly boiling the water. The tube is sealed while the steam is escaping. The instrument thus contains only water and aqueous vapor. When the liquid is poured into *B*, and *A* is placed in a freezing mixture, the vapor is largely condensed in *A* while more is rapidly formed in *B*. Crystals of ice soon form on the surface of the water in *B*.

(*b.*) Wet a block of wood and place a watch crystal upon it. A film of water may be seen under the central part of the glass. Half fill the crystal with sulphuric ether and rapidly evaporate it by blowing over its surface a stream of air from a small bellows. So much heat is rendered latent in the vaporization that the watch crystal is firmly frozen to the wooden block.

527. Condensation of Gases.—Gases may be condensed by union with some liquid or solid, by cold or by pressure. It has been recently shown that any known gas may be liquefied by cold and pressure. In any case, *the condensation of a gas renders sensible a large amount of heat.*

(*a.*) Sulphurous oxide (SO_2) previously dried, is easily liquefied by passing it through a U-tube immersed in a freezing mixture. When some of this liquid is placed upon mercury in a small capsule and rapidly evaporated by blowing over it a stream of air from a bellows, *the mercury is frozen* (§ 497).

(*b*.) The change of latent heat into sensible during the condensation of a gas is easily illustrated by the following experiment: Into a gas bottle, *A*, put a teacup full of small pieces of marble, and pour in enough water to cover them and to seal the lower end of the thistle tube. From the gas bottle lead a delivery tube to the lower part of a bottle, *B*, containing a thermometer, *t*. From this bottle lead a tube to the lower part of the bottle *C*, which contains a thermometer, *T*, with its lower part embedded in a teacup full of salts of tartar. Through the thistle tube of *A* pour muriatic acid, about a thimble-full at a time. Carbonic acid gas will be liberated and pass through *B* into *C*. There it unites with the potassium carbonate, changing it to potassium bi-carbonate. In this change from the aëriform to the solid condition, the carbonic acid gives up all its latent heat, as is shown by the remarkable rise of the thermometer in *C*. That this increase of temperature is not due to the sensible heat of a hot gas is shown by the fact that *t* is scarcely affected during the experiment.

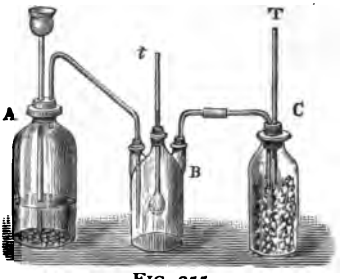


FIG. 255.

(*c*.) When the vapor is condensed to the liquid or solid form, the heat previously rendered latent is given out as sensible heat; that is, the energy of position is changed back to energy of motion. In coming together again, the particles yield the same amount of kinetic energy as was consumed in their separation.

528. The Latent Heat of Water.—If 1 lb. of water at 0° C. be mixed with 1 lb. of water at 80° C., we shall have two pounds of water at 40° C. But if 1 lb. of ice at 0° C. be mixed with 1 lb. of water at 80° C., we shall have two pounds of water at 0° C. The heat which might be used to warm the water from 0° to 80° C., has been used in melting a like weight of ice. Hence, by our definition, we see that the latent heat of water is 80° C. (or 144° F.) This means that *the amount of heat required to melt a quantity of ice without changing its tempera-*

ture is eighty times as great as the heat required to warm the same quantity of water one centigrade degree.

(*a*.) Because of this great latent heat of water, the processes of melting ice and freezing water are necessarily slow. Otherwise, the waters of our northern lakes might freeze to the bottom in a single night, while "the hut of the Esquimaux would vanish like a house in a pantomime," or all the snows of winter be melted in a single day with inundation and destruction.

529. The Latent Heat of Steam.—Experiment has shown that the amount of heat necessary to evaporate one pound of water would suffice to raise the temperature of 537 pounds of water 1° C. Hence we say that the latent heat of steam is 537° C. (or 967° F.). This means that *the amount of heat required to evaporate a quantity of water without changing its temperature is 537 times as great as the heat required to warm the same quantity of water one centigrade degree.*

(*a*.) When a pound of steam is condensed, 537 heat units (pound-centigrade) are liberated. In this we see an explanation of the familiar fact that scalding by steam is so painfully severe. Were it not for the latent heat of steam, when water reached its boiling point it would instantly flash into steam with tremendous explosion.

530. Problems and Solutions.—(1.) How many pounds of ice at 0° C. can be melted by 1 pound of steam at 100° C.? One pound of steam at 100° C., in condensing to water at the same temperature, parts with all its latent heat, or 537 heat units. The pound of water thus formed can give out 100 more heat units. Hence, the whole number of heat units given out by the steam in changing to water at 0° C., the temperature at which it can no longer melt ice, is 537 + 100 = 637.

Let x = the number of pounds of ice that can be melted. Each pound of ice melted will require 80 heat units. Hence, $80x$ = the number of heat units necessary. The heat to melt the ice must come from the steam.

Therefore $80x = 637$. $\therefore x = 7.96 +$ lbs. *Ans.*

(2.) How many pounds of steam at 100° C. will just melt 100 pounds of ice at 0° C.? If x represent the number of pounds of steam required, that quantity of steam at 100° C. will furnish $637x$ heat units. To melt 100 lbs. of ice, $(80 \times 100 =)$ 8,000 heat units will be required.

Hence, $637x = 8{,}000$. $\therefore\ x = 12.55 +$ lbs. *Ans.*

(3.) What weight of steam at 100° C. would be required to raise 500 pounds of water from 0° C. to 10° C.?

Let x = the number of pounds of steam required.

$(537 + 90)x = 500 \times 10$. $\therefore\ x = 7.97 +$ lbs. *Ans.*

(4.) If 4 lbs. of steam at 100 C. be mixed with 200 lbs. of water at 10° C., what will be the temperature of the water?

Let x = the temperature. In condensing to water at 100° C., the 4 lbs. of steam will give out $(537 \times 4 =)$ 2,148 heat units. This 4 lbs. of water will then give out $4(100 - x)$ heat units. Hence, the steam will impart $2{,}148 + 4(100 - x)$ heat units. The 200 lbs. of water in rising from 10° C. to $x°$ will absorb $200(x - 10)$ heat units.

Hence, $2{,}148 + 4(100 - x) = 200(x - 10)$. $\therefore\ x = 22.39°$ C. *Ans.*

531. Illustration of Specific Heat. — When the temperature of a body changes from 30° to 20°, the body loses just as much heat as it gained in passing from 20° to 30°. This heat lost by a cooling body may be measured, like any other energy, by the work it can perform. If equal weights of different bodies be raised to the same temperature, the amount of ice that each can melt will be proportional to the number of thermal units they severally contain. A pound of sulphur at 212° F. will melt $\frac{1}{3}$ as much ice as a pound of boiling water. Hence, it required only $\frac{1}{3}$ as much heat to heat the sulphur from the freezing point to 212° F., as it did to heat the water to the same temperature; in scientific phraseology, the specific heat of sulphur is $\frac{1}{3}$.

(*a.*) In an experiment of this kind, if the cooling substance change its condition, the latent heat set free as sensible heat must be taken into account. Special precaution must also be taken in measuring

the heat expended, to avoid melting of the ice by the heat of the surrounding air and making proper allowance for the heat expended in warming the apparatus itself. Fig. 256 represents a form of *calorimeter* frequently used in such experiments. *M* contains the heated body whose weight and temperature are known. *A* contains the ice to be melted, the liquid thus produced escaping by *D*. *B* is an ice jacket to prevent melting of the ice in *A* by the heat of the air.

FIG. 256.

532. Definition of Specific Heat.—*The specific heat of a body is the ratio between the quantity of heat required to warm that body one degree and the quantity of heat required to warm an equal weight of water one degree.*

(*a.*) It is very important to bear in mind that specific heat, like specific gravity, is a ratio; nothing more nor less. The specific heat of water, the standard, is unity. This ratio will be the same for any given substance, whatever the thermal unit or thermometric scale adopted.

533. Specific Heat Determined by Mixture.—One of the simplest methods of measuring specific heat is by mixture. Suppose, *e. g.*, that 3 kilograms of mercury at 100° C. are mixed with 1 kilogram of ice-cold water and that the temperature of the mixture is 9° C. How shall we find the specific heat of mercury?

Let x = the specific heat of the mercury, or the amount of heat lost by one kilogram of mercury for each degree of change of temperature. Then will

$3x$ = the number of heat units lost by the given amount of mercury for every degree of change of temperature, and 91 times $3x$, or

$273x$ = the number of heat units lost by the mercury in passing from 100° to 9° C.

The specific heat of water is 1. This multiplied by the number of kilograms of water taken is 1, which represents the number of

heat units gained by that quantity of water for each degree of change of temperature. Then will 9 represent the number of heat units gained by the water in passing from 0° to 9°. But no heat has been destroyed or wasted; what the mercury has lost, the water has gained.

	Mercury.	*Water.*
Specific heat	x	1
Weights taken	3	1
No. of degrees of change	91	9
Heat units	$273x$	= 9

$\therefore\ x = .033$, the specific heat of mercury.

534. Heated Balls Melting Wax.—The difference between bodies in respect to specific heat may be roughly illustrated as follows: small balls of equal weight, made severally of iron, copper, tin, lead and bismuth are heated to a temperature of 180° or 200° C. by immersing them in hot oil until they all acquire the temperature of the oil. They are then placed on a cake of beeswax about half an inch thick. The iron and copper will melt their way through the wax, the tin will nearly do so, while the lead and bismuth sink not more than half way through the wax.

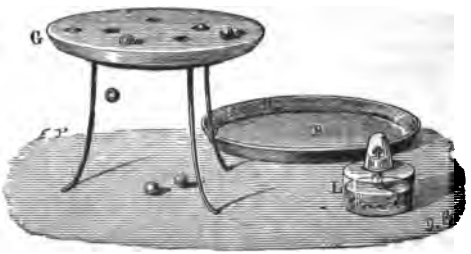


FIG. 257.

535. Reference Tables.—(1.) Specific Heat of some substances:

Hydrogen	3.4090	Iron	.1138
Water	1.0000	Copper	.0952
Ammonia (gas)	.5084	Silver	.0570
Air	.2375	Tin	.0562
Oxygen	.2175	Mercury	.0333
Sulphur	.2026	Lead	.0314
Diamond	.1469	Bismuth	.0308

(2.) Specific heat of some substances in different states:

	Solid.	*Liquid.*	*Aeriform.*
Water	.5050	1.0000	.4805
Bromine	.0843	.1060	.0555
Alcohol	.....	.5050	.4534
Ether	.....	.5467	.4797

536. Specific Heat of Water.—*Water in its liquid form has a higher specific heat than any other substance except hydrogen.* For this reason the ocean and our lakes are cooled and heated more slowly than the land and atmosphere. They thus modify sudden changes of temperature, and give rise to the well known fact that the climate of the sea-coast is warmer in winter and cooler in summer than that of inland places of the same latitude. The heat of summer is stored up in the ocean and slowly given out during the winter. This fact also explains a phenomenon familiar to those living on the borders of the ocean or great lakes. Because of its lower specific heat, the land becomes during the day more heated than the water. The air in contact with the land thus becomes more heated, expands, rises and forms an *upper* current from the land accompanied by a corresponding *under* current to the land, the latter constituting the welcome sea or lake breezes of summer. After sunset, however, the land cools more rapidly than the water, the process is reversed, and we have an under current from the land constituting the land breeze.

Exercises.

1. One kilogram of water at 40° C., 2 kilograms at 30° C., 3 kilograms at 20° C., and 4 kilograms at 10° C. are mixed. Find the temperature of the mixture.

2. One pound of mercury at 20° C. was mixed with one pound of

water at 0° C., and the temperature of the mixture was 0.634° C. Calculate the specific heat of mercury.

3. What weight of water at 85° C. will just melt 15 pounds of ice at 0° C.?

4. What weight of water at 95° C. will just melt 10 pounds of ice at −10° C.?

5. What weight of steam at 125° C. will melt 5 pounds of ice at −8° C. and warm the water to 25° C.?

6. How much mercury could be warmed from 10° C. to 20° C. by 1 kilogram of steam at 200° C.?

7. Equal masses of ice at 0° C. and hot water are mixed. The ice is melted and the temperature of the mixture is 0° C. What was the temperature of the water?

8. Ice at 0° C. is mixed with ten times its weight of water at 20° C. Find the temperature of the mixture. *Ans.* 11° C. nearly.

9. One pound of ice at 0° C. is placed in 5 pounds of water at 12° C. What will be the result?

10. Find the temperature obtained by condensing 10 *g.* of steam at 100° C. in 1 *Kg.* of water at 0° C.

11. A gram of steam at 100° C. is condensed in 10 grams of water at 0° C. Find the resulting temperature. *Ans.* 58° C. nearly.

12. If 200 *g.* of iron at 300° C. be plunged into 1 *Kg.* of water at 0° C., what will be the resulting temperature?

13. Find the specific heat of a substance, 80 *g.* of which at 100° C. being immersed in 200 *g.* of water at 10° gives a temperature of 20° C.

14. If 300 *g.* of copper at 100° C. be immersed in 700 *g.* of alcohol at 0° C., what will be the resulting temperature? (§ 535.)

15. What will be the result of mixing 5 ounces of snow at 0° C. with 23 ounces of water at 20° C.?

16. A pound of wet snow mixed with 5 pounds of water at 20° C. yields 6 pounds of water at 10° C. Find the proportions of snow and water in the wet snow.

17. What weight of mercury at 0° C. will be raised one degree by dropping into it 150 *g.* of lead at 400° C.?

18. Find the result of mixing 6 pounds of snow at 0° C. with 7 pounds of water at 50° C.

Recapitulation.—In this section we have considered the definition of Thermal Units; two Varieties of Molecular Energy; their mutual Convertibility; the definition of Latent Heat; the latent

heat of Fusion and of Solution; Freezing Mixtures; Solidification, and the Temperature of Solidification; Heat from Solidification; Change of Bulk during solidifying; the Latent Heat of Vaporization; the Condensation of Gases; the Latent Heat of Water and of Steam; illustration and definition of Specific Heat; specific heat Determined by Mixture; specific heat Determined by Melting Wax; tables of specific heat, and the Specific Heat of Water.

SECTION IV.

MODES OF DIFFUSING HEAT.

537. Diffusion of Heat.—Heat is diffused in three ways: by conduction, convection, and radiation. Whatever the mode of diffusion, there is a tendency to produce uniformity of temperature.

538. Conduction.—If one end of an iron poker be thrust into the fire, the other end will soon become too warm to be handled. It has been heated by conduction, the molecules first heated giving some of their heat to those adjacent, and these passing it on to those beyond. There was a transfer of motion from molecule to molecule. *The process by which heat thus passes from the hotter to the colder parts of a body is called conduction of heat.* The propagation is very gradual, and as rapid through a crooked as through a straight bar.

539. Differences in Conductivity.—If, instead of an iron poker, we use a glass rod or wooden stick, the end of the rod may be melted or the end of the stick

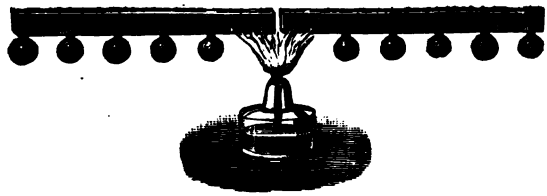


FIG. 258.

burned without rendering the other end uncomfortably warm. We thus see that some substances are good conductors of heat while some are not. Thrust a silver and a German silver spoon into the same vessel of hot water, and the handle of the former will become much hotter than that of the latter.

(*a.*) Fig. 258 represents a bar of iron and one of copper placed end to end so as to be heated equally by the flame of the lamp. Small balls (or nails) are fastened by wax to the under surfaces of the bars at equal distances apart. More balls can be melted from the copper than from the iron. The *number* of balls melted off, not the *rapidity* with which they fall, is the test of conductivity. The rapidity would depend more upon specific heat.

(*b.*) Relative thermal conductivity of some metals:

Silver	100	Iron	12
Copper	74	Lead	9
Gold	53	Platinum	8
Brass	24	German silver	6
Tin	15	Bismuth	2

The above-named metals arrange themselves in the same order with reference to the conduction of electricity, silver being the best and bismuth the poorest. This relation suggests a similarity of nature between these two agents.

540. Conductivity of Fluids.—*Liquids and aeriform bodies are poor conductors of heat.* The surface of a liquid may be intensely heated without sensibly affecting the temperature an inch below.

(*a.*) Cork the neck of a glass funnel and pass the tube of an inverted thermometer through the cork, or use an air thermometer, as shown in the figure. Cover the thermometer bulb to the depth of about half an inch with water. Upon the water pour a little sulphuric ether and ignite it. The heat of the flame will be intense enough to boil a small quantity of water held *over* it, but the thermometer below will be scarcely affected. Fasten a piece of ice at the bottom of a glass tube, and cover it to the depth of several inches with water. Hold the tube at an angle of about 45°, and apply the flame of a lamp below the upper part of the water. The water there may be made to boil without melting the ice. The conductivity of gases is probably lower than that of liquids.

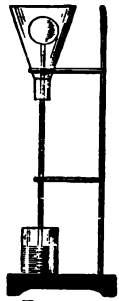


FIG. 259.

541. Convection.—Fluids (with the exception of mercury, which is a metal) being poor conductors, they cannot be heated as solids generally are. Water, *e.g.*, must be heated *from below;* the heated molecules expand and rise while the cooler ones descend to take their place at the source of heat. These currents in heating water may be made visible by dropping a small quantity of cochineal or oak sawdust into the vessel containing the water. *This method of diffusing heat, by actual motion of heated fluid masses, is called convection.* Expansion by heat and the force of gravity are essential to convection. Since aëriform bodies are expanded more by heat than liquids are, these currents of heated gases are more active than those of liquids. Hence the drafts of lamps and stoves, the existence of trade winds, etc.

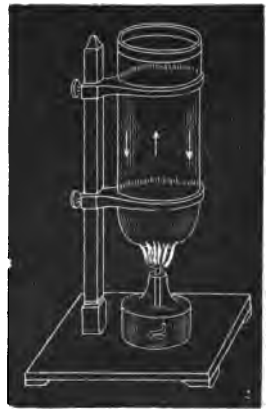


FIG. 260.

542. The Third Mode of Heat Diffusion.—When a hand is held over a heated stove, heat is carried to the hand by convection and given up to the hand by conduction. But when the hand is held before the stove it is also heated, not by conduction, for fluids have little conducting power; not by convection, for convection currents are ascending. How then does the heat get to the hand? The query comes to us with still greater force when we consider the transmission of the sun's heat to the earth, for the atmosphere can carry it by neither conduction nor convection. More important yet, how does the sun's heat reach the earth's atmosphere? This heat passes through the atmosphere without heating it. If along a poker thrust into the fire the hand be moved toward the stove, the temperature increases. If a person ascend through the atmosphere toward the sun the temperature diminishes. We have here a wholly new set of thermal phenomena, heat passing through a substance and leaving the condition of that substance unchanged.

543. Luminiferous Ether.—In the case of actual, mechanical energy, the rapid motion of bodies, *e. g.*, a vibrating guitar string, is partly carried off by the air in the shape of sound. When the sound reaches the auditory nerve it represents a certain amount of mechanical energy of motion which has been carried from the string by the air. *There is sufficient reason for believing that there is a medium pervading all space which carries off part of the invisible motions of molecules, just as the air carries off a portion of the motion of moving masses.* This medium, called the luminiferous ether, occupies all space. The gaps between the sun, the planets and their satellites are filled with this ether. "It makes the universe a whole and renders possible the intercommunication of light and energy between star and star."

544. Density and Elasticity of the Ether.—This ether is wonderful, not only in its incomprehensible vastness but equally so in its subtleness. While it surrounds the suns of unnumbered systems and fills all interstellar space, it also surrounds the smallest

particles of matter and fills intermolecular space as well. It is called luminiferous because it is the medium by which light is propagated, it serving as a common carrier for both heat and light. We have seen (§ 426) that the velocity of sound depends upon two considerations, the elasticity and the density of the medium. The enormous velocity with which the ether transmits heat and light as wave motion (about 186,000 miles *per* second), compels us to assume for the ether both extreme elasticity and extreme tenuity.

545. Radiant Heat.—We have seen that the molecules of a heated body are in a state of active vibration. The motion of these vibrating molecules is communicated to the ether and transmitted by it, as waves, with wonderful velocity. Thus, when you hold your hand before a fire, the warmth that you feel is due to the impact of these ether-waves upon your skin; they throw the nerves into motion, just as sound-waves excite the auditory nerve, and the consciousness corresponding to this motion is what we popularly call warmth. *Heat thus propagated by the ether, instead of by ordinary forms of matter, is Radiant Heat. The process of propagation is called radiation.*

546. The Transmission through a Vacuum.—*Radiant heat will traverse a vacuum.* We might infer this from the fact that the sun radiates heat to the earth. It may be also shown experimentally.

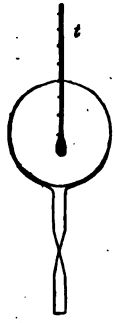


FIG. 261.

(*a.*) A thermometer is sealed air-tight in the bottom of a glass globe in such a way that the bulb is near the centre of the globe. The neck of the flask is to be about a yard long. The apparatus being filled with mercury and inverted over a mercury bath, a Torricellian vacuum is formed in the globe and upper part of the tube. The tube is then melted off above the mercury. When the globe is immersed in hot water, the thermometer immediately indicates a rise of tem-

perature. There is no chance for convection; conduction acts much more slowly.

547. Rectilinear Propagation.—*Radiant heat travels in straight lines through any uniform medium.*

(*a*.) Between any source of heat and a thermometer place several screens. If holes be made in the screens (See Fig. 272) so that a straight line from the source of heat to the thermometer may pass through them, the thermometer will be affected by the heat. By moving one of the screens so that its opening is at one side of this line, the heat is excluded. In a very warm day a person may step from a sunny into a shady place for the same reason. The heat that moves along a single line is called a ray of heat.

548. Radiation Equal in all Directions.—*Heat is radiated equally in all directions.* If an iron sphere or a kettle of water be heated, and delicate thermometers placed on different sides of it at equal distances, they will all indicate the same temperature.

549. Radiation Depends upon Temperature of the Source.—*The intensity of radiant heat is proportional to the temperature of the source.*

(*a*.) Near a differential thermometer, place a vessel of water 10° warmer than the temperature of the room. Notice the effect upon the thermometer. Heat the water 10° more and repeat the experiment at the same distance. Then heat the water 10° still more and repeat the experiment again. The effects upon the thermometer will be as the numbers one, two and three.

550. Effect of Distance.—*The intensity of radiant heat varies inversely as the square of the distance.*

(*a*.) Place the differential thermometer at a certain distance from the heated water and note the effect. Removing the thermometer to twice that distance the effect is only one-fourth as great, etc.

551. Incident Rays.—When radiant heat falls upon a surface it may be transmitted, absorbed or reflected. If transmitted, it may be refracted. Rock salt crystal transmits nearly all, reflects very little, and absorbs hardly any. Lampblack absorbs nearly all, reflects very little, and transmits none. Polished silver reflects nearly all, absorbs a little, and transmits none.

552. Diathermancy.—*Bodies that transmit radiant heat freely are called diathermanous; those that do not are called athermanous.* These terms are to heat, what transparent and opaque are to light. Rock salt is the most diathermanous substance known. Heat that is radiated from a non-luminous source, as from a ball heated below redness, is called *obscure* heat; while part of that radiated from a luminous source, as from the sun or from a ball heated to redness, is called *luminous* heat. Heat from a luminous source is generally composed of both luminous and obscure rays. (§ 652.)

553. Selective Absorption.—The power of any given substance to transmit heat varies with the nature of the heat or of its source. For example, glass, water or alum allows the sun's luminous heat rays to pass, while absorbing nearly all of the heat rays from a vessel filled with boiling water. In other words, these substances are diathermanous for luminous rays, but athermanous for obscure rays. The physical difference between luminous and obscure heat rays will subsequently be explained.

(*a.*) A solution of iodine in carbon bi-sulphide transmits obscure rays but absorbs luminous rays. By means of these substances, luminous and obscure rays may be sifted or separated from each other. Dry air is highly diathermanous; watery vapor is highly athermanous for obscure rays.

554. Reflection of Heat.—When radiant heat falls upon an athermanous body, part of it is generally absorbed and raises the temperature of the body. The rest is reflected, the energy still existing in the ether waves. *The angle of incidence equals the angle of reflection* (§ 97).

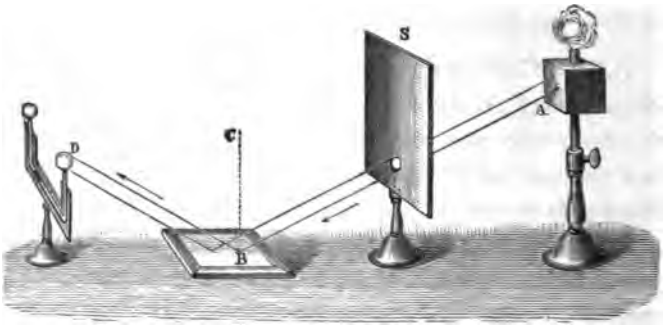


FIG. 262.

(*a.*) In Fig. 262, the source of heat at *A* is a Leslie's cube filled with hot water. *S* is an athermanous screen with an aperture for the passage of rays from *A* to the reflector *B*. The line *CB* is perpendicular to the reflector. When *D*, the bulb of the differential thermometer, is placed so that the angle *ABC* equals the angle *DBC*, the reflected rays will strike the bulb and raise the temperature.

555. Reflection by Concave Mirrors.—By the use of spherical or parabolic mirrors, remarkable heating effects may be produced. When parallel rays (like the sun's rays) strike directly upon such a mirror, they are reflected to a focus. Any easily combustible substance held at the focus may be thus ignited.

(*a.*) Two such mirrors may be placed as shown in Fig. 263. At the focus of one reflector place a hot iron ball; at the focus of the other, a bit of phosphorus or gun-cotton. If the apparatus be arranged with exactness, the combustible will be quickly ignited.

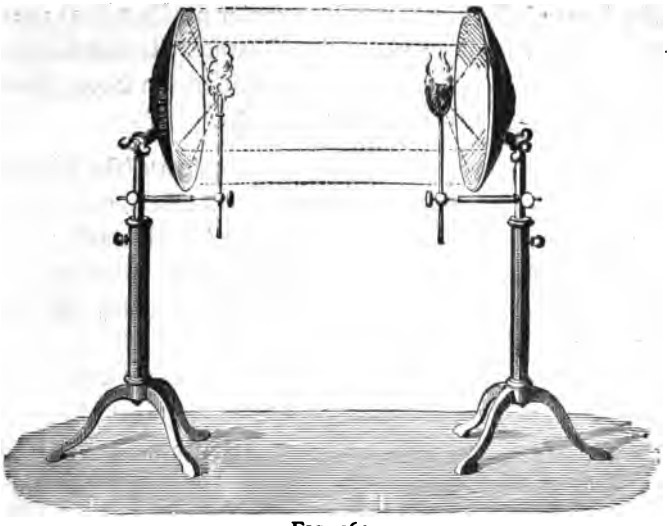


FIG. 263.

Replace the iron ball with a Leslie's cube containing hot water; at the focus of the other reflector place one bulb of the differential thermometer. The rise of temperature at this focus will be clearly shown, *even when the other bulb is nearer the source of heat than the focus is.*

556. Refraction of Heat.—When rays of heat fall obliquely upon a diathermanous body, they will be bent from a straight line on entering and leaving the body. *This bending of the ray is called refraction.* Many rays of heat may thus be concentrated at a focus, as in the case of a common burning-glass. By the aid of a spectacle-glass, the sun's rays may be made to ignite easily combustible substances. The refraction of obscure rays cannot be shown by a glass lens, since glass is athermanous for such rays. But if a rock-salt lens be held before a source of obscure heat, and the face of a thermopile placed at

the focus of the lens, the galvanometer needle will at once turn aside, showing a rise of temperature. If the face of the pile be placed anywhere else than at the focus, there will be no such deflection of the needle.

557. Change of Radiant into Sensible Heat.—Of all the rays falling upon any substance, only those that are absorbed are of effect in heating the body upon which they fall. The motion of the ether waves may be changed into vibrations of molecules of ordinary matter, and thus produce sensible heat, but the same energy cannot exist in waves of ether and in ordinary molecular vibrations at the same time.

(*a.*) Phosphorus or gun-cotton may be ignited by solar rays at the focus of a lens made of clear *ice*. The heat rays pass through the ice without melting it. It is only when the radiation is stopped that the energy of the ray can warm anything.

558. Determination of Absorbing, Reflecting and Radiating Powers.—For experiments in determining the absorbing, reflecting and radiating powers of solids, the apparatus generally used consists of a Leslie's cube, concave mirrors of different materials, and a differential thermometer or a thermopile. The Leslie's cube is a box about three inches on each edge, the sides being made of, or covered with, different materials, to show their differences in radiating power. The cube filled with hot water is placed before the reflector, and a bulb of the thermometer is placed at the focus. By turning different faces of the cube toward the mirror, the relative radiating powers are determined. By using different mirrors, the reflecting powers are determined. By coating the bulb with different substances, their absorbing powers are determined. The relative radiating powers of several common substances are as given below:

Lampblack	100	Tarnished lead	45
Paper	98	Mercury	20
Crown glass	90	Gold, silver, copper	12

559. Mutual Relations of Absorptiou, Reflection and Radiation.—By means like those men-

tioned in the last paragraph, it has been shown that *good absorbents are good radiators and poor reflectors, and vice versa;* that the radiating power of a body depends largely upon the nature of its surface; that smoothing and polishing the surface increases reflecting power, and diminishes absorbing and radiating power; that roughening and tarnishing the surface increases the absorbing and radiating powers, and diminishes the reflecting power. *The powers of absorption and radiation go hand in hand.* (§§ 654, 655.)

(*a.*) Make a thick paint of a teaspoonful of lampblack and a little kerosene oil. With this, paint the right-hand face of the left-hand bulb (tin can of the differential thermometer described in Appendix M). Provide another oyster can and paint one side with the lampblack. Fill this third can with boiling water and place it on the wooden strips, *midway* between the two tin bulbs, the two blackened surfaces facing each other. The heat radiated and absorbed by the two blackened surfaces will exceed the heat radiated and absorbed by the two equal unpainted surfaces that face each other. The movement of the colored alcohol in the tube will show this to be true.

560. Sympathetic Vibrations.—The relation between radiation and absorption of heat is closely analogous to the relation between the radiation and absorption of sound. If a set of sound waves fall upon a string capable of producing similar waves, the string is set in motion and the sound waves weakened (§ 443). When ether waves of a given kind fall upon a body whose molecules are able to vibrate at the same rate, and thus to reproduce similar waves, the kinetic energy is transferred from the ether to the molecules, the molecules are heated, the radiant energy *absorbed.* This ability to absorb wave motion of any particular kind, implies the ability to reproduce the same kind of waves. It therefore is easily seen

that *a body that can absorb any particular kind of heat rays can radiate the same kind.*

Note.—It will be seen further on, that obscure heat rays differ from light *only in the matter of wave length.* Most of the phenomena of one may be shown to pertain to the other. Absorption, radiation, reflection, transmission and refraction of rays follow the same laws, whether the agent be called heat or light. Other phenomena, such as interference and polarization, more satisfactorily studied with luminous rays, have been produced with obscure rays. It should be borne in mind that the most delicate instruments yet made are far less sensitive to obscure heat than is the eye to light. A candle flame may be seen a mile away; any one might well be pleased with an instrument that would detect its heat at the distance of a rod.

QUESTIONS.

1. Good conductors feel warmer or cooler to the touch than poor conductors of the same temperature. Why?
2. Why is it so oppressively warm when the sun shines *after* a summer shower?
3. Why is there greater probability of frost on a clear than on a cloudy night?
4. Can a good absorbent be a good reflector of heat? Is a good absorbent a good radiator, or otherwise?
5. Explain why the glass covering of a hot-bed or conservatory renders the confined air warmer than the atmosphere outside.
6. From your own experience, decide which is the better conductor of heat, linen or woolen goods, oil-cloth or carpet.
7. Why are the double walls of ice-houses filled with sawdust? Why do fire-proof safes have double walls inclosing plaster-of-Paris or alum?
8. Why do furnace men, firemen and harvesters wear woolen clothing? Explain the use of double windows.
9. How may heat be diffused? How is the surface of the earth and how is the atmosphere heated? Can you boil water in a vessel with heat applied from above? Why?

Recapitulation.—In this section we have considered Conduction; the conductivity of Fluids; Convection; the Luminiferous Ether, its Den-

sity and Elasticity; Radiant Heat, and Radiation; Diathermancy; Selective Absorption; Reflection from plane and concave surfaces; Refraction; the Change from radiant into sensible heat; the determination of Absorbing, Reflecting and Radiating Powers, and their Mutual Relations; Sympathetic Vibrations.

SECTION V.

THERMODYNAMICS.

561. Definition of Thermodynamics.—*Thermodynamics is the branch of science that considers the connection between heat and mechanical work.* It has especial reference to the numerical relation between the quantity of heat used and the quantity of work done.

562. Correlation of Heat and Mechanical Energy.—We know that heat is not a form of matter because *it can be created in any desired quantity.* We must continually remember that it is a form of energy. When heat is produced some other kind of energy must be destroyed. Conversely, when heat is destroyed, some other form of energy is created. Considered as heat merely, this agent may be annihilated; considered as energy, it may only be transformed. The most important transformations of energy are those between heat and mechanical energy. The process of working these transformations will be considered directly. It is to be noticed, however, that while we may be able to effect a *total* conversion of mechanical energy into heat, we are not able to bring about a total conversion of heat into mechanical energy.

563. Heat from Percussion.—A small iron rod placed upon an anvil may be heated to redness by repeated blows of a hammer. The energy of the moving mass is

broken up, so to speak, and distributed among the molecules, producing that form of molecular motion that we call heat. The same transformation was illustrated in the kindling of a fire by the "flint and steel" of a century ago. It may be experimentally illustrated by the "air-syringe."

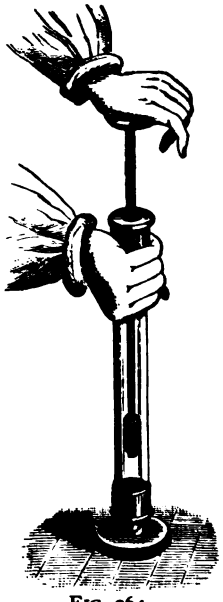


FIG. 264.

(*a*.) The air-syringe consists of a cylinder of metal or glass and an accurately fitting piston. By suddenly driving in the piston, the air is compressed and heat developed. A bit of gun cotton previously placed in the cylinder may thus be ignited. If the cylinder be made of glass, and a bit of ordinary cotton dipped in sulphuric ether be used, repeated flashes of light may be produced by successive combustions of ether vapor. The fumes of one combustion must be blown away before the next combustion is attempted.

564. Heat from Friction.— Common matches are ignited and cold hands warmed by the heat developed by friction. It is said that some savages kindle fires by skilfully rubbing together well-chosen pieces of wood. In the case of the axles of railway cars and ordinary carriages, this conversion of mechanical energy into heat is not so difficult as its prevention. Lubricants are used to diminish the friction and prevent the waste of energy due to the undesirable transformation. A railway train is really stopped by the conversion of its motion into heat. When this has to be done quickly, the change is hastened by increasing the friction by means of the brakes. Examples of this change are matters of every day experience.

(*a*.) Attach a brass tube 10 *cm*. long, about 2 *cm*. in diameter and closed at the bottom, to a whirling table. Partly fill the tube with cold water and cork the open end. Press the tube between two pieces of board hinged together as shown in the figure. The boards

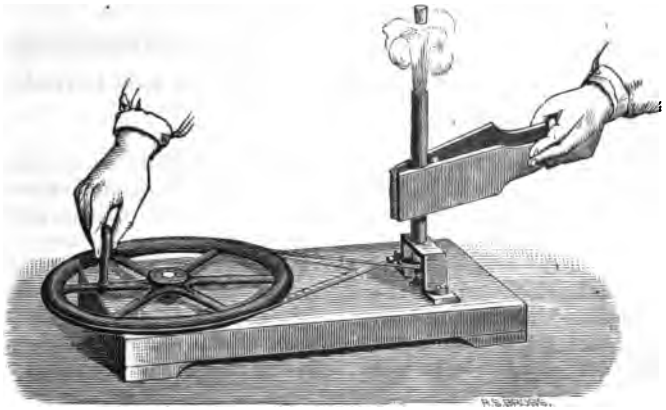


FIG. 265.

should have two grooves for the reception of the tube; the inner faces of the boards may be covered with leather. When the machine is set in motion the friction warms and soon *boils the water*. The steam drives out the cork with explosive violence.

565. First Law of Thermodynamics.—*When heat is transformed into mechanical energy or mechanical energy into heat, the quantity of heat equals the quantity of mechanical energy.* This principle is the corner-stone of thermodynamics. It is a particular case under the more general law of the Conservation of Energy.

566. Joule's Equivalent.—It is a matter of great importance to determine the numerical relation between heat and mechanical energy; to find the equivalent of a heat unit in units of work. This equivalent was first ascertained by Dr. Joule, of Manchester, England. His

experiments were equal in number and variety to the importance of the subject. He showed that the mechanical value of a heat unit is *772 foot-pounds, referring to the Fahrenheit degree; 1390 foot-pounds referring to the centigrade degree.* This is expressed by saying that the "mechanical equivalent" of heat is 772 or 1390 foot-pounds. (§ 514 [*a*].)

(*a*.) A change in the unit of weight will not affect these numbers, *which must not be forgotten.* If the heat unit be "kilogram-Fahrenheit," the equivalent will be 772 foot-kilograms; if the thermal unit be "gram-centigrade," the equivalent will be 1390 foot-grams. A change in the unit of length will work a change in the number representing the equivalent. If the equivalent for a "kilogram-centigrade" heat unit be desired in kilogrammeters instead of foot-kilograms, the number 1390 must be divided by the ratio between the values of a foot and a meter, becoming thus *424 kilogrammeters.*

567. The Use of Joule's Equivalent.—The use of the mechanical equivalent of heat may be well shown by the solution of a problem.

(*a*.) If a cannon-ball weighing 192.96 pounds and moving with a velocity of 2000 feet per second, be suddenly stopped and all of its kinetic energy converted into heat, to what temperature would it warm 100 pounds of ice-cold water?

$$\text{Kinetic energy} = \frac{wv^2}{2g} = \frac{192.96 \times 4000000}{64.32} = 12000000 \text{ foot-pounds.}$$

$12000000 \div 772 = 15544 +$ heat units.

$15544 \div 100 = 155.44$ heat units for each pound of water. This would raise the temperature 155.44° F., leaving it at 187.44° F. *Ans.*

(*b*.) Knowing the weight of the earth and its orbital velocity, we may easily compute the amount of heat that would be developed by the impact of the earth against a target strong enough to stop its motion. The heat thus generated from the *kinetic energy* of the earth would be sufficient to fuse if not vaporize it, equalling that derivable from the combustion of fourteen globes of coal each equal to the earth in size. After the stoppage of its orbital motion it would surely be drawn to the sun with continually increasing velocity. The heat instantaneously developed from

this impact of the planetary projectile would equal that derivable from the combustion of 5600 globes of coal each equal to the earth in size. This is the measure of the *potential energy* of the earth considered as a mass separated from the sun.

568. Chemical Affinity.—We have already seen that there are forces in nature compared with which the force of gravity is insignificant. (Read carefully the first paragraph in this chapter.) When coal is burned, the carbon and oxygen particles rush together with tremendous violence, energy of position being converted into energy of motion. The molecular motions produced by this clashing of particles constitute heat and have a mechanical value.

569. Heating Powers.—If a pound of carbon be burned, the heat of the combustion would raise about 8000 pounds of water 1° C. In like manner, the combustion of a pound of hydrogen would yield about 34000 heat units (pound-centigrade).

(*a.*) The following table shows the heating powers of several substances when burned in oxygen:

Hydrogen	34,462	Alcohol (C_2H_6O)	6,850
Marsh gas (CH_4)	13,063	Phosphorus	5,747
Petroleum	12,300	Carbon protoxide (CO)	2,403
Carbon	8,080	Sulphur	2,220

(*b.*) The calorific powers mentioned above may be adapted to Fahrenheit degrees by multiplying them respectively by $\frac{5}{9}$. As they stand, the numbers represent the number of times its own weight of water that could be warmed 1° C. by burning the substance in oxygen.

570. The Steam-Engine.—The steam-engine is a machine for utilizing the tension of steam. Its essential parts are a boiler for the generation of steam, and a cylinder for the application of the tension to a piston.

(*a.*) As in the case of water-power the production of mechanical kinetic energy involves the fall of water from a higher to a lower level, so in the case of steam-power the production of visible energy involves the fall of heat from a higher to a lower temperature.

571. Single-Acting Engine.—In a single-acting steam-engine, the piston is pushed one way by the tension of the steam. The steam is then condensed and the piston driven back by atmospheric pressure. Such engines have gone out of use and have only an historical interest.

572. Double-Acting Engine.—In a double-acting steam-engine, the steam is admitted to the cylinder alternately above and below the piston. This alternate admission of the steam is accomplished by means of a sliding-valve. The sliding-valve is placed in a steam-chest, *S*, which is fastened to the side of the cylinder *C*.

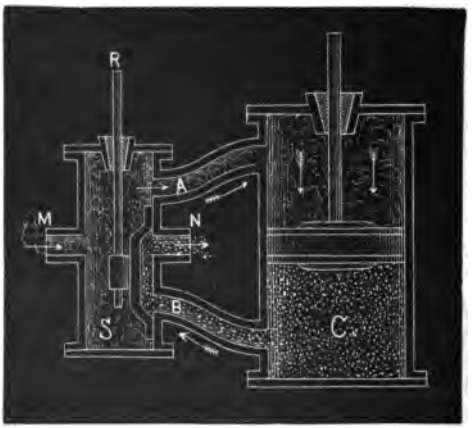


FIG. 266.

(*a.*) In the figure, the steam-chest is represented as being placed at a distance from the cylinder; this is merely for the purpose of making plain the communicating passages to and from the chest. Steam from the boiler enters at *M*, passes through *A* to the

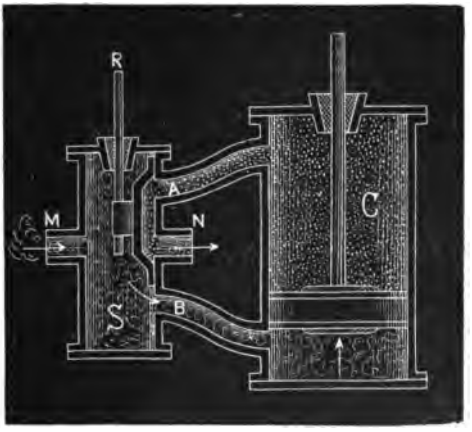


FIG. 267.

cylinder, where it pushes down the piston as indicated by the arrows. The steam below the piston escapes by *B* and *N*. As the piston nears the opening of *B* in the cylinder, the sliding-valve is raised, by means of the rod *R*, to the position indicated in Fig. 267. Steam now enters the cylinder by *B* and pushes up the piston. The steam above the piston escapes by *A* and *N*. As the piston nears the opening of *A* in the cylinder, the sliding-valve is pushed down by *R* and the process is thus repeated. The piston-rod and the sliding-valve rod work through steam-tight packing-boxes.

573. The Eccentric.—By means of a crank or similar device, illustrated in common foot-power machinery like the turning-lathe, scroll-saw, or sewing-machine, the alternating rectilinear motion of the piston-rod is changed into a continuous rotary motion. A circular shaft is thus given a revolution for every to-and-fro movement of the piston. This shaft generally carries an eccentric for working the sliding-valve rod *R*. The eccentric (Fig. 268) consists of a circular piece of metal, *e*, rigidly attached to the shaft of the engine *S*, in such a position that the centre of the piece does not coincide with the centre of the shaft.

The eccentric turns within a collar, which is fastened to the frame *T*. Every turn of the shaft moves the eccentric with its collar and the frame *T*, backward and forward into the two positions indicated by the full and dotted lines of

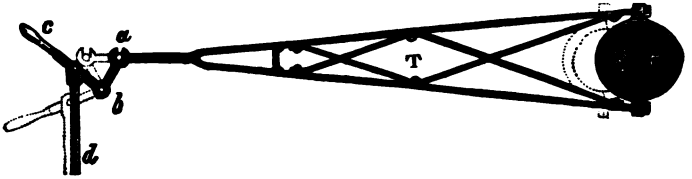


FIG. 268.

Fig. 268. The point *a* may be fastened directly to the sliding-valve rod or through the agency of the bent lever *abc*, as the circumstances of the case render more desirable.

574. The Governor and Fly-Wheel.—The admission of steam through *M* (Fig. 267) is regulated by a throttle-valve worked by a governor (Fig. 269). A vertical shaft is given a rotary motion by the machinery. To the top of this rod are hinged two arms carrying heavy balls, *bb*.

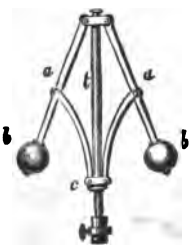


FIG. 269.

From these arms, supports extend to a collar, *c*, surrounding the vertical rod. This collar is connected with a valve controlling the admission of steam to the valve-chest in such a way that when the collar rises the valve closes. As the machinery increases its speed, the balls revolve more rapidly about the vertical axis and tend to fly further apart (§ 74). In doing so, they raise the collar and partly close the valve, diminishing the supply of steam. The machinery is thus made to slacken its speed, the balls fall, and the valve opens. The rapidity of motion can therefore be confined within

the limits due to closing the throttle-valve and throwing it wide open. Further than this, smoothness of motion is secured by attaching a heavy fly-wheel to the shaft of the engine. A little reflection will show that the fly-wheel also acts as an *accumulator of energy.*

575. The Safety-Valve.—The safety-valve is a necessary part of every steam-boiler. It consists of a valve, *V*, held down over an opening in the top of the boiler by means of a spring or a loaded lever of the second class. The force with which the valve is held down is to be less than the strength of the boiler, *i. e.*, the force must be such that the valve will open before the tension of the steam becomes dangerous. On steamboats, the weight, *W*, is generally *locked in position* by a Government officer.

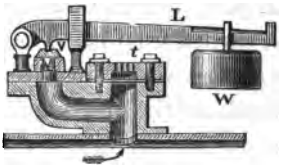


FIG. 270.

576. Non-Condensing Engines.—When the steam is forced out at *N* (Fig. 267), it has to overcome an atmospheric pressure of 15 pounds to the square inch. This must be deducted from the total tension of the steam to find the *available* power of the engine. Such an engine is known as a non-condensing engine. It may be recognized by the escape of steam in puffs. It is generally a high-pressure engine. The railway locomotive is a high-pressure, non-condensing engine.

577. Condensing Engines.—The steam may be conducted from the exhaust pipe *N* (Fig. 267) to a chamber called a condenser. Steam from the cylinder and a jet of cold water being admitted at the same time, a vacuum is

formed and the loss of energy due to atmospheric pressure is avoided. Such an engine is known as a condensing, or low-pressure engine.

(*a*.) Low-pressure engines are always condensing engines. A low-pressure engine will do more work with a given amount of fuel than a high-pressure non-condensing engine will, is less liable to explosion, and causes less wear and tear to the machinery. But it must be larger, more complicated, more costly, and less portable.

578. Heat and Work of Steam-Engines.— More heat is carried to the cylinder of a steam-engine than is carried from it. The piston does work at every stroke, and this work comes from the heat that disappears. Every stroke of the piston annihilates heat. Careful experiments show that the heat destroyed and the work performed are in strict agreement with Joule's equivalent. With a given supply of fuel, the engine will give out less heat when it is made to work hard than when it runs without doing much work.

EXERCISES.

1. The mechanical equivalent of heat is 1390 foot-pounds. What is it in kilogrammeters?

2. Find the weight of water that may be warmed 15° C. by burning 1 of sulphur in oxygen.

3. What weight of water would be heated from 0° C. to 1° C. by the combustion of one gram of phosphorus?

4. One gram of hydrogen is burned in oxygen. To what temperature would a kilogram of water at 0° C. be raised by the combustion?

5. From what height must a block of ice at 0° C. fall that the heat generated by its collision with the earth shall be just able to melt it?

6. From what height must it fall that the heat generated may be sufficient to vaporize it?

7. To what height could a ton weight be raised by utilizing all the heat produced by burning 5 lbs. of pure carbon?

8. Find the height to which it could be raised if the coal had the following percentage composition:

$$C = 88.42; \quad H = 5.61; \quad O = 5.97.$$

9. To what temperature would a cannon-ball weighing 150 lbs. and moving 1920 feet per sec., warm 2000 lbs. of water at 32° F., if its motion were suddenly converted into heat?

10. (*a.*) How many pounds of water can be evaporated by 80 lbs. of pure carbon? (*b.*) If applied to iron, how many pounds could be heated from 0° F. to 2000° F.?

11. With what velocity must a 10-ton locomotive move to give a mechanical energy equivalent to the heat necessary to convert 4800 lbs. of ice at 0° C. to steam at 100° C.?

12. An 8-lb. ball is shot vertically upward in a vacuum with a velocity of 2000 feet. How many pounds of water may be raised from the freezing to the boiling point by the heat generated when it strikes the earth on its descent?

13. (*a.*) From what height must water fall in order to raise its own temperature 1° C. by the destruction of the velocity acquired, supposing no other body to receive any of the heat thus generated? (Answer to be given in meters.) (*b.*) How far must mercury fall to produce the same effect? (Specific heat of mercury = .0333.)

14. With a velocity of how many *cm.* per second must a leaden bullet strike a target that its temperature may be raised 100° C. by the collision, supposing all the energy of the motion to be spent in heating the bullet? (Specific heat of lead = .0314; $g. = 980\,cm.$ § 127.)

15. A steam-engine raises a ton weight 386 ft. How many heat units are thus expended?

16. A 64-pound cannon-ball strikes a target with a velocity of 1400 feet per second. Supposing all the heat generated to be given to 60 pounds of water, how many centigrade degrees would the temperature of the water be raised?

17. A cannon-ball weighing 7 pounds strikes an iron target with a velocity of 1000 feet per second. Suppose the whole of the motion to be converted into heat and the heat uniformly distributed through 70 pounds of the target, determine the change of temperature thus produced. (Specific heat of iron = .1138.)

18. The specific heat of tin is .056 and its latent heat is 25.6 Fahrenheit degrees. Find the mechanical equivalent of the amount of heat needed to heat 6 pounds of tin from 374° F. to its melting point 442° F. and to melt it.

19. A lead ball strikes a target with a velocity of 1000 feet per second. Show that the heat generated would be sufficient to fuse the lead. (See § 497 and § 535.)

20. The mechanical equivalent of heat is 772 foot-pounds, reference being made to the Fahrenheit degree. It is also given as 424 kilogrammeters, reference being made to the centigrade degree. Show that the two values are approximately identical.

Recapitulation.—In this section we have considered the definition of Thermodynamics; the Correlation of Heat and Mechanical Energy; heat from Percussion; from Friction; First Law of thermodynamics; Joule's Equivalent and its Use; Chemical Affinity and the Heating Powers of various substances; the Single and Double-acting Steam-engines; the Eccentric, Governor and Safety-valve; Condensing and Non-condensing Engines; the relation between Heat and Work in the steam-engine.

Review Questions and Exercises.

1. Lead melts at 326° C. In melting it absorbs about as much heat as would warm 5.37 times its weight of water 1° C. What numbers will replace the 326 and 5.37 when the Fahrenheit scale is used?

2. What is the difference between the temperatures −40° C. and −40° F.?

3. A quantity of gas at 100° C. and under a pressure of 750 *mm.* of mercury measures 4500 *cu. cm.* What will be its volume at 200° C. and under a pressure of 76 *cm.* of mercury?

4. Over how high a ridge can you carry water in a siphon, where the minimum range of the barometer is 27 inches? Explain.

5. (*a.*) What is Specific Gravity? (*b.*) How do you find that of solids heavier than water? (*c.*) What principle is involved in your method?

6. (*a.*) Of what physical force is lightning a manifestation? (*b.*) Give some plain directions for the construction of lightning-rods, with reasons for your directions.

7. Give the fundamental principle of mechanics, and illustrate its application by one of the mechanical powers.

8. (*a.*) What are the essential properties of matter? (*b.*) What is a pendulum; (*c.*) to what use is it principally applied, and (*d.*) what are the laws by which it is governed?

9. (*a.*) In what ways may two musical tones differ? (*b.*) What is the physical cause of the difference in each case?

10. (*a.*) Convert −3° F. and 77° F. into C. readings; (*b.*) 18° C. and 20° C. to F. readings.

11. (*a.*) To what temperature should a liter of oxygen at 0° C. be raised in order to double its volume, the pressure remaining constant? (*b.*) Give reasons for your answer.

12. (*a.*) What is meant by the boiling point of a liquid? (*b.*) State some circumstances that cause it to vary.

13. A kilogram each of water, iron and antimony, at 0° C. are heated ten minutes by the same source of heat, and are then found to be 1° C., 9° C. and 20° C. respectively. Required the specific heat of each.

14. (*a.*) Define latent heat. (*b.*) Describe a method of determining the latent heat of water. (*c.*) Describe the cooling and freezing of a lake.

15. (*a.*) If 2 kilograms of water should be suddenly stopped after falling 212 metres, how much heat would be generated? (*b.*) Describe the essential parts of a steam-engine.

16. (*a.*) How many cubic feet of water will be displaced by a boat weighing two tons? (*b.*) How many of salt water of sp. gr. 1.09? (*c.*) How does a noise differ from a musical sound?

17. The sp. gr. of alcohol is .80; that of mercury 13.6. When a mercury barometer indicates a pressure of 30 inches, what will be the height of an alcohol barometer column?

18. (*a.*) Describe the ordinary force-pump; (*b.*) explain the use of its essential parts.

19. (*a.*) Give the formulas for changing thermometric readings from F. to C., and *vice versa*. (*b.*) Explain the graduation of two kinds of thermometers. (*c.*) Define increment of velocity.

20. (*a.*) What is distillation, and upon what fact does the process depend? (*b.*) What is latent heat? (*c.*) Illustrate the conversion of sensible into latent heat. (*d.*) On what does the pitch of sound depend?

21. (*a.*) Define boiling and boiling point. (*b.*) What is the rate of expansion for gases? (*c.*) Will water boil at a lower temperature at the sea level or on the top of a mountain? Why? (*d.*) What constitutes the *timbre* of a sound? (*e.*) Give the formulas for the wheel and axle.

22. (*a.*) If the pressure remain the same, how much will 546 *cu. cm.* of hydrogen expand when heated from 0° C. to 10° C.? (*b.*) How much work may be performed by a ball weighing 64.32 lbs., moving with a velocity of 50 ft. per second? (*c.*) When has water the greatest density?

23. Show that to raise the temperature of a pound of iron from 0° C. to 100° C. requires more energy than to raise seven tons of iron a foot high.

CHAPTER IX.

LIGHT.

SECTION I.

THE NATURE, VELOCITY AND INTENSITY OF LIGHT.

579. What is Light?—*Light is that mode of motion which is capable of affecting the optic nerve. The only physical difference between light and radiant heat is one of wave length.*

(*a.*) We have seen that the vibrations of air particles in a sound wave are to and fro in the line of propagation. In the case of radiant heat and light, the ether particles vibrate to and fro across the line of propagation. Vibrations in a sound wave are *longitudinal;* those of a heat or light wave are *transversal.*

580. Luminous and Non-Luminous Bodies.—Bodies that emit light of their own generating, as the sun or a candle, are called luminous. Bodies that merely diffuse the light that they receive from other bodies are said to be non-luminous or illuminated. Trees and plants are non-luminous.

(*a.*) Visible bodies may be luminous or illuminated, but in either case they send light in every direction from every point in their surfaces. In Fig. 271 we see represented a few of the infinite number of lines of light starting from *A*, *B* and *C*, three of the

infinite number of points in the surface of a visible object. *If the infinite number of lines were drawn from each of the infinite number of points,* there would be no vacant spaces in the figure; the rays really intersect at every point from which the object is visible.

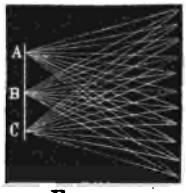


FIG 271.

581. Transparent, Translucent and Opaque Bodies.—Bodies are transparent, translucent or opaque according to the degree of freedom which they afford to the passage of the luminiferous waves. Transparent bodies allow objects to be seen distinctly through them, *e. g.*, air, glass and water. Translucent bodies transmit light, but do not allow bodies to be seen distinctly through them, *e. g.*, ground glass and oiled paper. Opaque bodies cut off the light entirely and prevent objects from being seen through them at all. The light is either reflected or absorbed. So much of the radiant energy as is neither reflected nor transmitted is changed to absorbed heat.

582. Luminous Rays.—A single line of light is called a ray. The ray of light is perpendicular to the wave of ether. The ray may, without considerable error, be deemed the path of the wave.

583. Luminous Beams and Pencils.—A collection of parallel rays constitutes a beam; a cone of rays constitutes a pencil. The pencil may be converging or diverging. If a beam or pencil should dwindle in thickness to a line, it would become a ray.

584. Rectilinear Motion of Light.—A medium is homogeneous when it has an uniform composition and density. *In a homogeneous medium, light travels*

in straight lines. This is a fact of incalculable scientific and otherwise practical importance.

(*a.*) The familiar experiment of "taking sight" depends upon this fact, for we see objects by the light which they send to the eye. We cannot see around a corner or through a crooked tube. A beam of light that enters a darkened room by a small aperture, marks an illuminated course that is perfectly straight.

(*b.*) This fact may be illustrated by providing two or three perforated screens and arranging them as shown in Fig. 272, so that the holes and a candle flame shall be in the same straight line.

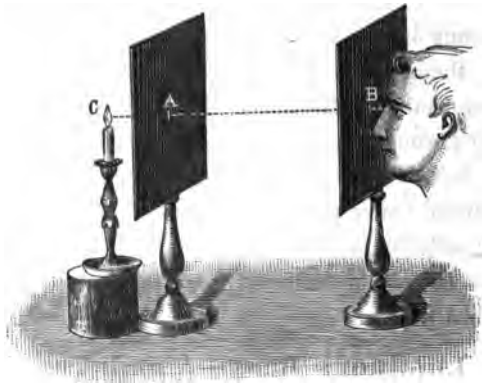


FIG. 272.

When the eye is placed in this line behind the screens, light passes from the flame to the eye; the flame is visible. A slight displacement upward, downward or sidewise of the eye, the flame or any screen, cuts off the light and renders the flame invisible.

(*c.*) Prepare a piece of wood, $1\frac{1}{2} \times 2\frac{1}{2} \times 18$ inches, taking care that the edges are square. Saw it into six pieces, each three inches long. Prepare three pieces of wood, $3 \times 4 \times \frac{1}{8}$ inches. Place three postal cards one over the other on a board, and pierce them with a fine awl or stout needle, $\frac{1}{4}$ inch from the end and $1\frac{1}{2}$ inch from either side of the card. With a sharp knife pare off the rough edges of the holes, and pass the needle through each hole to make the edges smooth and even. Over the $\frac{1}{2} \times 3$ inch surface of one of the blocks place the unperforated end of one of the postal cards, and over this place one of the 3×4 inch pieces, so that their lower edges shall be

even. Tack them in this position. Make thus two more similar screens. The three screens, with a bit of candle three inches long, placed upon one of the remaining blocks, furnishes the material for the experiment above. Save the screens and three blocks for future use. (See Fig. 280.)

585. Inverted Images.—If light from a highly-illuminated body be admitted to a darkened room through a small hole in the shutter and there received upon a white screen, it will form an inverted image of the object upon the screen. Every visible point of the illuminated object sends a ray of light to the screen. Each ray brings the color of the point which sends it and prints the color upon the screen. As the rays are straight lines, they cross at the aperture; hence, the inversion of the image. The image will be distorted unless the screen be perpendicular to the rays. The darkened room constitutes a *camera obscura*. The image of the school playground at recess is very interesting and easily produced.

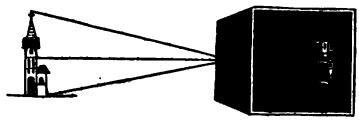


FIG. 273.

(*a.*) Place a lighted candle about a meter from a white screen in a darkened room. (The wall of the room will answer for the screen.) Pierce a large pin-hole in a card, and hold it between the flame and the screen. An inverted image of the flame will be found upon the screen.

(*b.*) Bore an inch hole in one side of a wooden box; cover this opening with tinfoil, and prick the tinfoil with a needle. Place a lighted candle within the box; close the box with a lid or a shawl, and hold a paper screen before the hole in the tinfoil. Move the screen backward and forward, and notice that in any position the size of the object is to the size of the image as the distance from the aperture to the object is to the distance from the aperture to the image.

(*c.*) Cover one end of a tube, 10 or 12 *cm.* long, with tinfoil; the other end with oiled paper. Prick a pin-hole in the tinfoil and turn

it toward a candle flame. The inverted image may be seen upon the oiled paper. The size of the image will depend upon the distance of the flame from the aperture. The apparatus rudely represents the eye, the pin-hole corresponding to the pupil and the oiled paper to the retina. (Almost any housekeeper will give you an empty tin can. Place it upon a hot stove just long enough to melt off one end, thrust a stout nail through the centre of the other end, cover the nail hole with tinfoil, and you will have the greater part of the apparatus.)

586. Shadows.—Since rays of light are straight, opaque bodies cast shadows. *A shadow is the darkened space behind an opaque body from which all rays of light are cut off.* It is sometimes called the perfect shadow or the umbra. If the source of light be a point, the shadow will be well defined; if it be a surface, the shadow will be surrounded by an imperfect shadow called a penumbra. The penumbra is the darkened space behind an opaque body from which some of the rays (the rays from a part of the luminous surface) are cut off.

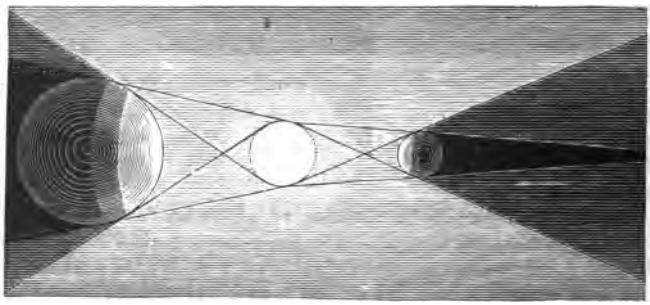


FIG. 274.

(*a.*) Hold a lead pencil between the flame of an ordinary lamp and a sheet of paper held about two feet (61 *cm.*) from the lamp: (1.) When the *edge* of the flame is toward the pencil; (2.) When the *side* of the flame is toward the pencil.

(*b.*) Describe the shadow cast by a sphere and a luminous point. By a sphere and a luminous globe of equal size. By a sphere and a luminous globe of greater size, *e. g.*, the earth's shadow. A solar eclipse takes place whenever the eye of the observer is in the shadow of the moon. Figure the shadow of the moon. Where must the observer be to see a total eclipse of the sun? To see an ordinary eclipse (when the sun appears crescent-shaped)? To see an annular eclipse?

587. Visual Angle.—*The angle included between two rays of light coming from the extremities of an object to the centre of the eye is called the visual angle.* This angle measures the apparent length of the line that subtends it. Any cause that increases the visual angle of an object increases its apparent size. Hence the effect of magnifying-glasses. From

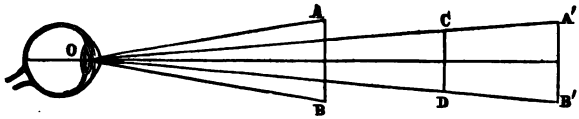


FIG. 275.

Fig. 275 we see that equal lines may subtend different visual angles, or that different lines may subtend the same angle.

588. Velocity of Light.—Light traverses the ether with a velocity of about 186,000 miles or about 298 million meters per second. This was first determined about 200 years ago by Roemer, a Danish astronomer.

(*a.*) At equal intervals of 42h. 28m. 36s., the nearest of Jupiter's satellites passes within his shadow and is thus eclipsed. This phenomenon would be seen from the earth at equal intervals if light traveled instantaneously from planet to planet. Roemer found that when the earth was farthest from Jupiter the eclipse was seen 16 min. 36 sec. later than when the earth was nearest Jupiter. But Jupiter and the earth are nearest each other when they are on the

same side of the sun and in a straight line with the sun (conjunction), and farthest from each other when they are on opposite sides of the sun and in a straight line with that luminary (opposi-

FIG. 276.

tion). Hence, Roemer argued that it requires 16 min. 36 sec. for light to pass over the diameter of the earth's orbit, from E to E'. This distance being approximately known, the velocity of light is easily computed.

(*b.*) The velocity of light has been measured by other means, giving results that agree substantially with the result above given. When astronomers accurately determine the mean distance of the earth from the sun, the velocity of light will be accurately known.

(*c.*) It would require more than 17 years for a cannon-ball to pass over the distance between the sun and the earth; light makes the journey in 8 min. 18 sec. For the swiftest bird to pass around the earth would require three weeks of continual flight; light goes as far in less than one-seventh of a second. For terrestrial distances, the passage of light is practically instantaneous (§ 425).

589. Effect of Distance upon Intensity.—*The intensity of light received by an illuminated body varies inversely as the square of its distance from the source of light.*

(*a.*) Let a candle at S be the source of light; A, a screen one foot square and a yard from S; B, a screen two feet square two yards from S; C, a screen three feet square three yards from S. It will easily be seen that A will cut off all the light from B and C. If now A be removed, the quantity of light which it received, no more and no less, will fall upon B. If now B be removed, the quantity of light which previously illuminated A and B will fall upon C. We thus see the same number of rays successively illu-

minating, one, four and nine square feet. One square foot at *B* will receive one-fourth, and one square foot at *C* will receive one-ninth as many rays as one square foot at *A*. The light being diffused over a greater surface is correspondingly diminished in intensity.

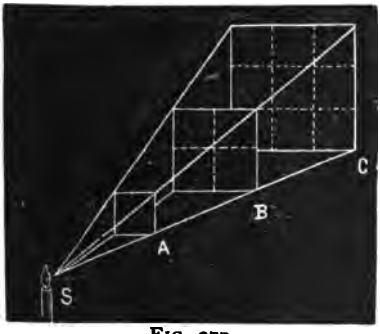


FIG. 277.

(*b*.) The experiment may be tried by placing the large screen at *A* and tracing the outline of the shadow with a pencil, then placing the screen successively at *B* and *C*, tracing the shadow each time. The experiment will be more satisfactory if a perforated screen be placed at *S*.

EXERCISES.

1. A coin is held 5 feet from a wall and parallel to it. A luminous point, 15 inches from the coin, throws a shadow of it upon the wall. How does the size of the shadow compare with that of the coin?

2. (*a*.) What is the velocity of light? (*b*.) How was it determined?

3. (*a*.) How are the intensities of two lights compared? (*b*.) Define light. (*c*.) Give your idea of the carrier of radiant heat and light.

4. (*a*.) Define luminous, transparent, opaque, beam and pencil. (*b*.) How could you show that light ordinarily moves in straight lines? (*c*.) Explain the formation of inverted images in a dark room.

5. (*a*.) What are shadows? (*b*.) By figures, illustrate shadows when the intercepting body is greater, equal to and less than the luminous body, and explain. (*c*.) What is the visual angle?

Recapitulation.—In this section we have considered the Nature of Light; Luminous, Illuminated, Transparent, Translucent and Opaque bodies; Rays, Beams and Pencils of light; that Light Moves in Straight Lines; Inverted Images and Shadows; the Visual Angle; the Velocity and Intensity of light.

SECTION II.

REFLECTION OF LIGHT.

Note.—The heliostat, or *porte-lumière*, is composed of one or more mirrors, by means of which a beam of light may be thrown in any desired direction. The instrument may be had of apparatus manufacturers at prices ranging from $12 upward. Directions for making one may be found in Mayer & Barnard's little book on "Light," published by D. Appleton & Co. It is very desirable that the instrument be secured in some way.

590. Reflection.—If a sunbeam enter a darkened room by a hole in the shutter, as at *A*, and fall upon a

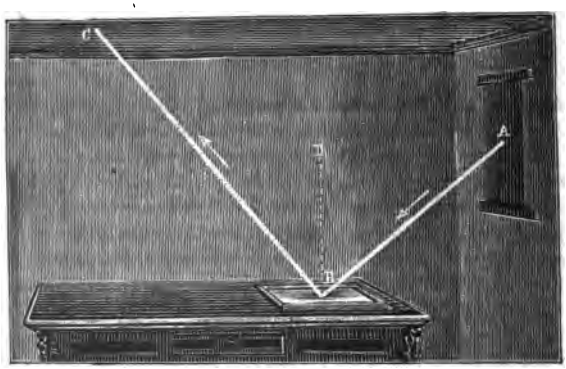


FIG. 278.

polished plane surface, as at *B*, it will be continued in a different direction, as toward *C*. *AB* is called the incident beam and *BC* the reflected beam (§ 97). The incident and the reflected beams are in the same medium, the air. *A change in the direction of light without a change in its medium is called reflection of light.*

591. Laws of Reflection.—The reflection of light

from polished surfaces is in accordance with the following laws:

(1.) *The angle of incidence is equal to the angle of reflection.*

(2.) *The incident and reflected rays are both in the same plane, which is perpendicular to the reflecting surface.*

(*a*.) Fill a basin to the brim with mercury or with water blackened with a little ink. In this liquid suspend by a thread a small weight of greater specific gravity than the liquid used (§ 253). The plumb-line will be perpendicular to the liquid mirror. Let the plumb-line hang from the middle of a horizontal meter or yard-

FIG. 279.

stick. Place the tip of a candle flame opposite one of the divisions of the stick, and place the eye in such a position that the image of the top of the flame will be seen in the direction of the foot of the plumb-line. Mark the point where the line of vision (*i. e.*, the reflected rays) crosses the meter-stick. It will be found that this point and the tip of the flame are equally distant from the middle of the stick. From this it follows (*Olney's Geometry*, Art. 342) that the angles of incidence and of reflection are equal.

(*b*.) Fig. 279 represents a vertical semicircle graduated to degrees, with a background of black velvet. A mirror at the centre is furnished with an index set perpendicular to its plane; both mirror and index can be turned in any direction desired. A ray of light from any brilliant source is allowed to enter the tube at the base, in the direction of the centre. By means of a little smoke from brown paper, the paths of the incident and reflected rays are easily shown to a large class.

(*c*.) Place two of the screens and the three extra blocks mentioned in § 584 in position, as shown in Fig. 280. At the middle of the middle block place a bit of window glass, painted on the under side with black varnish. On the blocks that carry the screens place bits of glass, *n* and *o*, of the same thickness as the black mirror on the middle block. Place a candle flame near the hole in one of the screens, as shown in the figure. Light from the candle will pass through *A*, be reflected at *m*, and pass through *B*. Place the eye in such a position that the spot of light in the mirror may be seen through *B*. Mark the exact spot in the mirror with a needle held in place by a bit of wax. Place a piece of stiff writing paper upright upon *m* and *n*, mark the position of *B* and of *m*, and draw on the paper a straight line joining these two points. The angle between this line and the lower edge of the paper coincides with the angle *Bmn*. Reverse the paper, placing it upon

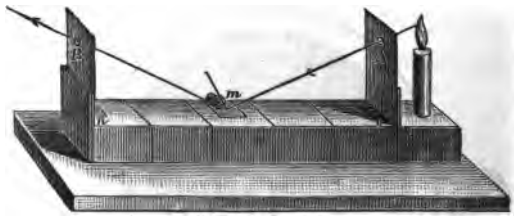


FIG. 280.

m and *o*. It will be found that the same angle coincides with *Amo*. *Amo* and *Bmn* being thus equal, the angle of incidence equals the angle of reflection.

592. Diffused Light.—Light falling upon an opaque body is generally divided into three parts: the first is regularly reflected in obedience to the laws above; the second is irregularly reflected or diffused; the third is absorbed. The irregular reflection is due to the fact that the bodies are not perfectly smooth, but present little protuberances that scatter the light in all directions, and thus render them visible from any position. Light regularly reflected gives an image of the body from which it came before reflection; light irregularly reflected gives an image

of the body that diffuses it. A perfect mirror would be invisible. *Luminous bodies are visible on account of the light that they emit; non-luminous bodies are visible on account of the light that they diffuse.*

(*a.*) If a beam of light fall upon a sheet of drawing paper, it will be scattered and illuminate a room. If it fall upon a mirror, nearly all of it will be reflected in a definite direction, and intensely illuminate a part of the room. Place side by side upon a board a piece of black cloth (not glossy), a piece of drawing paper and a piece of looking-glass. In a darkened room, allow a beam of sunlight to fall upon the cloth and notice the absorption. Let it fall upon the paper, and notice the diffusion of the light and its effects. Let it fall upon the looking-glass, and notice the regular reflection and its effects. Move the board so that the cloth, paper and glass shall pass through the beam in quick succession, and notice the effects.

(*b.*) In the darkened room place a tumbler of water upon a table; with a hand-mirror reflect a sunbeam down into the water; the tumbler will be visible. Stir a teaspoonful of milk into the water, and again reflect the sunbeam into the liquid; the whole room will be illuminated by the diffused light, the tumbler of milky water acting like a luminous body.

593. Invisibility of Light.—*Rays of light that do not enter the eye are invisible.* A sunbeam entering a darkened room is visible because the floating dust reflects some of the rays to the eye. If the reflecting particles of dust were absent the beam would be invisible.

(*a.*) Take any convenient box, about 60 *cm.* (2 *ft.*) on each edge, provide for it a glass front, and, at each end, a glass window about 10 *cm.* (4 inches) square. Place it on a table in a darkened room, and, with the heliostat, send a solar beam through the windows. Standing before the glass front of the box, this beam may be traced from the heliostat to the box, through the box and beyond it. Open the box, smear the inner surfaces of its top, back and bottom with glycerine, and close the box air-tight. Allow it to remain quiet a few days; the dust in the box will be caught by the glycerine and the confined air thus freed from particles capable

of reflecting light. Then send another solar beam from the heliostat through the two windows of the box. Standing as before, the beam may be traced to the box and beyond it, but within the box all is darkness.

594. Apparent Direction of Bodies.—Every point of a visible object sends a cone of rays to the eye. The pupil of the eye is the base of the cone. *The point always appears at the place where these rays seem to intersect* (*i. e.*, at the real or apparent apex of the cone). If the rays pass in straight lines from the point to the eye, the apparent position of the point is its real position. If these rays be bent by reflection, or in any other manner, *the point will appear to be in the direction of the rays as they enter the eye.* No matter how devious the path of the rays in coming from the point to the eye, this important rule holds good.

595. Plane Mirrors; Virtual Images.—If an object be placed before a mirror, an image of it appears behind the mirror. Inasmuch as the rays of the cone mentioned in § 594 do not actually converge back of the mirror, there can be no *real* image there. As there really is no image behind the mirror, we call it a *virtual* image. All virtual images are optical illusions, and are to be clearly distinguished from the *real* images to be studied soon. *Each point of this image will seem to be as far behind the mirror as the correspond-*

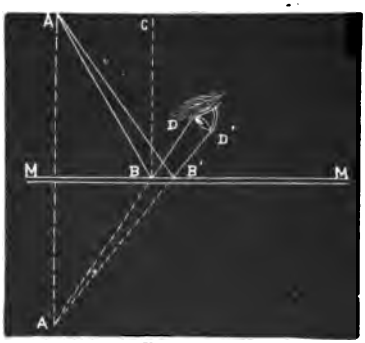


FIG. 281.

ing point of the object is in front of the mirror. Hence, images seen in still, clear water are inverted.

(*a.*) In Fig. 281, let A represent a luminous point; MM, a mirror; AA' and BC, lines perpendicular to the mirror. Rays from A enter the eye at DD'. The angle ABC = the angle CBD (§ 591). The angle ABC = the angle BAA' (*Olney's Geometry*, Art. 150). Therefore the angle CBD = the angle BAA'. The angle CBD = the angle $BA'A$ (*Olney*, 152). Therefore the angle BAA' = the angle $BA'A$. Hence $AM = A'M$ (*Olney*, 287). In other words, A' is as far behind the mirror as A is in front of it.

(*b.*) Place a jar of water 10 or 15 *cm.* back of a pane of glass placed upright on a table in a dark room. Hold a lighted candle at the same distance in front of the glass. The jar will be seen by light transmitted through the glass. An image of the candle will be formed by light reflected by the glass. The image of the candle will be seen in the jar, giving the appearance of a candle burning in water. The same effect may be produced in the evening by partly raising a window and holding the jar on the outside and the candle on the inside.

596. Reflection of Rays from Plane Mirrors.—If the incident rays be parallel, the reflected rays will be parallel. If the incident rays be diverging, the reflected rays will be diverging; they will seem to diverge from a point as far behind the reflecting surface as their source is in front of that surface (See Fig. 281). If the incident rays be converging, the reflected rays will be converging; they will converge at a point as far in front of the mirror as the point at which they were tending to converge is behind the mirror.

597. Construction for the Image of a Plane Mirror.—The position of the image of an object may be determined by locating the images of several well-chosen points in the object and connecting these images.

(*a.*) In Fig. 282, let AB represent an arrow; MN, the reflecting surface of a plane mirror, and E the eye of the observer. From

A, draw *Aa* perpendicular to *MN* and make *ad* equal to *Ad*. Then will *a* indicate the position of the image of *A*. From *B*, draw *Bb* perpendicular to *MN* and make *bc* equal to *Bc*. Then will *b* indicate the position of the image of *B*. By connecting *a* and *b* we locate the image of *AB*. Draw *aE*, *bE*, *Ao* and *Bi*. *AoE* represents one ray of the cone of rays from *A* that enters the eye; *BiE* represents one ray of a similar cone from *B*. Draw a similar figure on a larger scale, representing the eye at *C*. Test your figure by seeing if the angle of incidence is equal to the angle of reflection. In all such constructions, represent the direction of the rays by arrow-heads, as shown in Fig. 282.

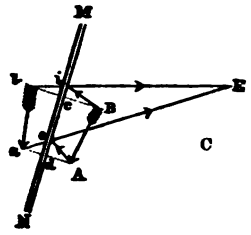


FIG. 282.

598. Multiple Images.—By placing two mirrors facing each other, we may produce multiple images of an object placed between them. *Each image acts as a material object with respect to the other mirror, in which we see an image of the first image.* When the mirrors are placed so as to form an angle with each other, the number of images becomes limited, being one less than the number of times that the included angle is contained in four right angles. The mirrors will give three images when placed at an angle of 90°; five at 60°; seven at 45°.

(*a*.) When the mirrors are placed at right angles the object and the three images will be at the corners of a rectangle as shown at *A*, *a*, *a'* and *a''*.

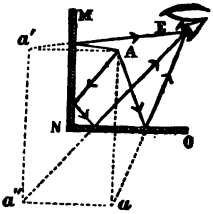


FIG. 283.

599. Concave Mirrors.—A spherical concave mirror may be considered as a small part of a spherical shell with its inner surface highly polished. Let *MN* (Fig. 284) represent the section of such a concave spherical mir-

ror, and C the centre of the corresponding sphere. C is called the *centre of curvature;* A is the centre of the mirror. A straight line of indefinite length drawn from A through C, as ACX, is called the *principal axis* of the mirror. A straight line drawn from any other point of the mirror through C, as JCd, is called a *secondary axis.* The point F, midway between A and C, is called the *principal focus.* The distance AF is the focal distance of the mirror; the focal distance is, therefore, one-half the radius of curvature. The angle MCN is called the aperture of the mirror.

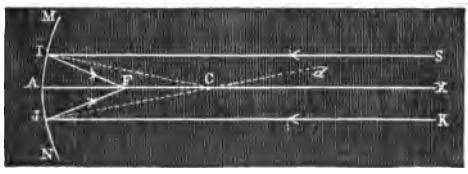


FIG. 284.

(*a.*) A curved surface may be considered as made up of an infinite number of small plane surfaces. Thus, a ray of light reflected from any point on a curved mirror may be considered as reflected from a plane tangent to the curved surface at the point of reflection. This reflection then takes place in accordance with the principles laid down in § 591. It should be borne in mind that the radii drawn from C to points in the mirror as I and J are perpendicular to the mirror at these points. Thus, the angles of incidence and reflection for any ray may be easily determined.

600. Effect of Concave Mirrors.—*The tendency of a concave mirror is to increase the convergence or to decrease the divergence of incident rays.*

(*a.*) If the divergence be that of rays issuing from the principal focus, the mirror will exactly overcome it and reflect them as parallel rays. If the divergence be greater than this, viz., that of rays issuing from a point nearer the mirror than the principal focus, the mirror cannot wholly overcome the divergence, but will diminish it.

The reflected rays will still diverge, but not so rapidly as the incident rays. If the divergence be less than that first mentioned, viz., that of rays issuing from a point further from the mirror than the principal focus, the divergence will be changed to convergence and a real focus will be formed.

601. The Principal Focus.—The focus of a concave mirror is the point toward which the reflected rays converge. All incident rays parallel to the principal axis will, after reflection, converge at the principal focus. *The principal focus is the focus of rays parallel to the principal axis.* The rays will be practically parallel when their source is at a very great distance, *e. g.*, the sun's rays. Solar rays coming to the human eye do not diverge a thousandth of an inch in a thousand miles.

(*a.*) Above we stated that parallel rays would be made to converge at the principal focus of a spherical concave mirror. This is only approximately true; it is strictly true in the case of a parabolic mirror. In order that the difference between the spherical and the parabolic mirror may be reduced to a minimum, the aperture of a spherical mirror must be small. The case is somewhat analogous to the coincidence of a circular arc of small amplitude with the cycloidal curve (§ 144, *a*). A source of light placed at the focus of a parabolic mirror will have its rays reflected in truly parallel lines. The head lights of railway locomotives are thus constructed. Parabolic mirrors would be more common if it were not so difficult to make them accurately.

602. Conjugate Foci.—Rays diverging from a luminous point in front of a concave spherical mirror and at a distance from the mirror greater than its focal distance, will converge, after reflection, at another point. The focus thus formed will be in a line drawn through the luminous point and the centre of curvature. In other words, if the luminous point lie in the principal axis, the focus will also; if the luminous point lie in any secondary axis, the focus will lie in the same secondary axis. The distinction be-

tween principal and secondary axes is almost wholly one of convenience. Rays diverging from B will form a focus at b. The angle of incidence being necessarily equal to the

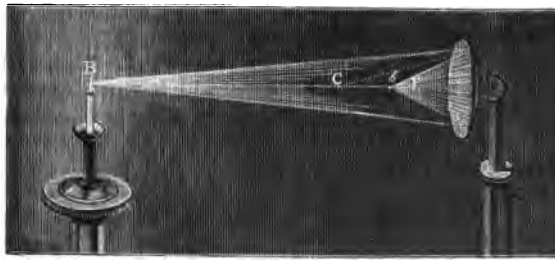


FIG. 285.

angle of reflection, it is evident that rays diverging from b would form a focus at B. On account of this relation between two such points, they are called conjugate foci. Therefore, *conjugate foci are two points so related that each forms the image of the other.*

603. Construction for Conjugate Foci.—In the case of concave mirrors, to locate the conjugate focus of a luminous point, it is necessary to find the point at which at least two reflected rays really or apparently intersect. The method may be illustrated as follows:

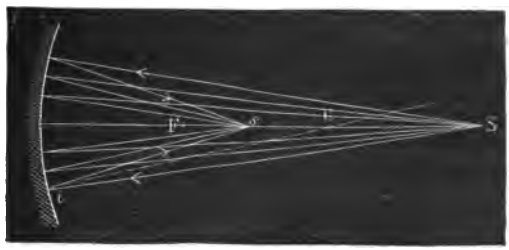


FIG. 286.

(1.) Let S (Fig. 286) represent the luminous point whose conjugate focus is to be located. It may or may not lie in the principal axis. Draw the axis for the point S, *i.e.*, a line from S through C,

the centre of curvature, to the mirror. This line represents one of the infinite number of rays sent from *S* to the mirror. As this incident ray is perpendicular to the mirror, the reflected ray will coincide with it. (Angles of incidence and of reflection = 0.) The conjugate focus must therefore lie in a line drawn through *S* and *C*. Draw a line representing some other ray, as *Si*. From *i*, the point of incidence, draw the dotted perpendicular *iC*. Construct the angle *Cis* equal to the angle *CiS*. Then will *is* represent the direction of the reflected ray. The focus must also lie in this line. The intersection of this line with the line drawn through *SC* marks the position of *s*, the conjugate focus of *S*.

(2.) If the reflected rays be parallel, of course no focus can be formed. If they be divergent, produce them back of the mirror as dotted lines (Fig. 287) until they intersect. In this case the focus will be virtual, because the rays only seem to meet. In the other cases the focus was real, because the rays actually did meet.

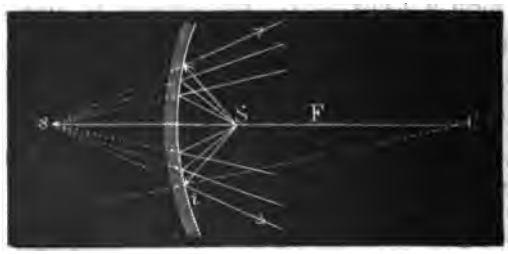


FIG. 287.

(3.) With a radius of 4 *cm.*, describe ten arcs of small aperture to represent the sections of spherical concave mirrors. Mark the centres of curvature and principal foci, and draw the principal axes. Find the conjugate foci for points in the principal axis designated as follows: (1.) At a distance of 1 *cm.* from the mirror. (2.) Two *cm.* from the mirror. (3.) Three *cm.* from the mirror. (4.) Four *cm.* from the mirror. (5.) Six *cm.* from the mirror. Make five similar constructions for points not in the principal axis. Notice that each effect is in consequence of the equality between the angle of incidence and the angle of reflection.

604. Formation of Images.—Concave mirrors give rise to two kinds of images, real and virtual. After

learning what has been said concerning conjugate, real and virtual foci, the formation of these images will be easily understood. The image of an object is determined by finding the images of a number of points in the object.

605. Construction for Real Images Formed by Concave Mirrors.—(1.) The method may be illustrated as follows; Let AB represent an object in front of a concave mirror, at a distance greater than the radius of curvature. Draw Ax, the secondary axis for the point A. The conjugate focus of A will lie in this line (§ 603 [1]). From the infinite number of rays sent from A to the mirror, select, as the second, the one that is parallel to the principal axis. This ray, after reflection at i, will pass through the principal focus (§ 601). The reflected rays, iF and xA (secondary axis for A), will intersect at a, which is the con-

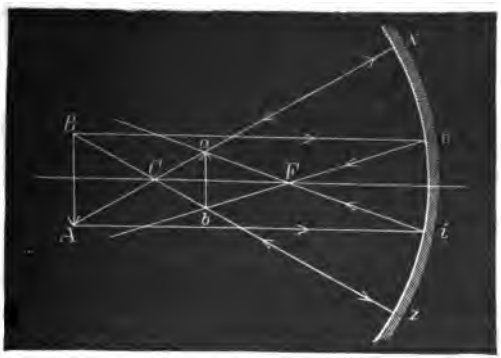


FIG. 288.

jugate focus for A. In similar manner, b, the conjugate focus for B, may be found. Points between A and B will have their conjugate foci between a and b.

(2.) If the eye of the observer be placed far enough back of the image thus formed for all of the image to lie between the eye and the mirror, it will receive the same impression from the reflected rays as if the image were a real object. All of the rays from any point in the object, as A, that fall upon the mirror, intersect after reflection at a, the conjugate focus. These reflected rays, after intersecting at a, form a divergent pencil. A cone of these rays thus diverging from a enters the eye. They originally diverged

from *A*, but *as they enter the eye*, they diverge from *a*. Hence the effect produced (§ 594).

(3.) From the similar triangles, *ABC* and *abC*, it is evident that the linear dimensions of the object and of its image are directly proportional to their distances from the centre of curvature. It may also be proved that the length of the object is to the length of the image as the distance of the object from the principal focus is to the focal distance of the mirror.

(4.) Since the lines that join corresponding points of object and image cross at the centre of curvature, the real images formed by concave mirrors are always inverted.

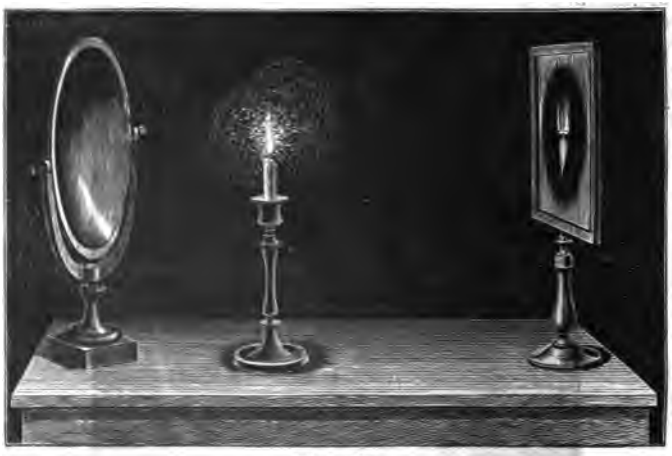


FIG. 289.

606. Projection of Real Images by Concave Mirrors.—The real image formed by a concave mirror may be rendered visible even when the eye of the observer is not in the position mentioned in the last article, by projecting it upon a screen. In a darkened room, let a candle flame be placed in front of a concave mirror, at a distance from it greater than the focal distance. Incline the mirror so that the flame shall not be on the principal axis. Place a paper screen at the conjugate focus of any

point in the luminous object. The proper position for the screen may easily be found by trial. Shield the screen from the *direct* rays of the flame by a card painted black. The inverted image may be seen by a large class. If the image fall between the mirror and the candle, the screen should be quite small.

607. Description of Real Images Formed by Concave Mirrors.—(1.) If the object be at the principal focus there will be no image. Why? (You can find out by trying a construction for the image (§ 605). (2.) If the object be between the principal focus and the centre of curvature, the image will be beyond the centre, inverted and enlarged. The nearer the object is to the principal focus, the larger and the further removed the image will be. (3.) When the object is at the centre, the image is inverted, of the same size as the object and at the same distance from the mirror. (4.) When the object is not very far beyond the centre of curvature, the image will be inverted, smaller than the object, and between the centre and the principal focus. (5.) When the object is at a very great distance, all of the rays will be practically parallel; there will be but one focus, and consequently no image.

(*a*.) For each of these five cases construct the images. The third case may be prettily illustrated as follows: In front of the mirror, at a distance equal to the radius of curvature, place a box that is open on the side toward the mirror. Within this box hang an inverted bouquet of bright-colored flowers. The eye of the observer is to be in the position mentioned in § 605 (2). By giving the mirror a certain inclination, easily determined by trial, an image of the invisible bouquet will be seen just above the box. A glass vase may be placed upon the box so that it may seem to hold the imaged flowers.

608. Construction for Virtual Images formed by Concave Mirrors.—Let AB represent an object in front of a concave mirror at a distance from it less than the focal distance. Draw the secondary axes for the points A and B, and produce them back of the mirror as dotted lines. From A and B, draw the incident rays Ao and Bi, parallel to the principal axis. After reflection they will pass through the principal focus (§ 601.) Produce these rays back of the mirror as dotted lines until they intersect the prolongations of the secondary axes at a and b, which will be the virtual conjugate foci for A and B. The conjugate foci for other points in AB will be between a and b. Therefore, if the object be between the principal focus and the mirror, the image will be virtual, erect and enlarged.

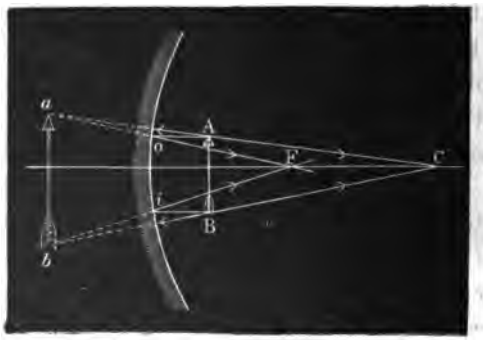


FIG. 290.

609. Images of the Observer formed by a Concave Mirror.—A person at a considerable distance before a concave mirror, sees his image, real, inverted and smaller than the object. As he approaches the centre of curvature, the image increases in size. As the observer moves from the centre to the principal focus, the image is formed back of him and is, therefore, invisible to him. As he moves from the principal focus toward the mirror, the image becomes virtual, erect and magnified, but gradually growing smaller. The eye will not always recognize real images as being in front of the mirror. It may some-

times be aided in this respect by extending the outspread fingers between the image and the mirror.

610. Convex Mirrors.—In convex mirrors, the foci are all virtual; the images are virtual, erect and smaller than their objects. The foci may be found and the images determined by the means already set forth. The construction is made sufficiently plain by Fig. 291.

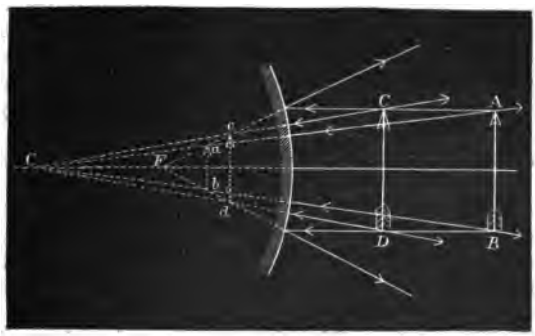


FIG. 291.

Note.—In constructions for curved mirrors, we have chosen two particular rays for each focus sought; one perpendicular to the mirror, the other parallel to the principal axis. This was only for the sake of convenience. Any two or more incident rays might have been taken and the direction of the reflected rays determined by making the angle of reflection equal to the angle of incidence.

EXERCISES.

1. What must be the angle of incidence that the angle between the incident and the reflected rays shall be a right angle?

2. The radius of a concave mirror is 18 inches. Determine the conjugate focus for a point on the principal axis, 12 inches from the mirror.

3. (*a.*) Illustrate by a diagram the image of an object placed at the principal focus of a concave mirror; (*b.*) of one placed between that focus and the mirror; (*c.*) of one placed between the focus and the centre of the mirror.

4. (*a.*) What kind of mirror always makes the image smaller than the object? (*b.*) What kind of a mirror may make it larger or smaller, and according to what circumstances?

5. Rays parallel to the principal axis fall upon a convex mirror. Draw a diagram to show the course of the reflected rays.

6. (*a.*) Why do images formed by a body of water, appear inverted? (*b.*) What is the general effect of concave mirrors upon incident rays?

7. A person, placed at a considerable distance before a concave mirror, sees his image. (*a.*) How does it appear to him? He approaches the mirror and the image changes. (*b.*) Describe the changes that take place until he sees a virtual image of himself.

8. A man stands before an upright plane mirror and notices that he cannot see a complete image of himself. (*a.*) Could he see a complete image by going nearer the mirror? Why? (*b.*) By going further from it? Why?

9. When the sun is 30° above the horizon, its image is seen in a tranquil pool. What is the angle of reflection?

10. A person stands before a common looking-glass with the left eye shut. He covers the image of the closed eye with a wafer on the glass. Show that when, without changing his position, he opens the left and closes the right eye, the wafer will still cover the image of the closed eye.

11. The distance of an object from a convex mirror is equal to the radius of curvature. Show that the length of the image will be one-third that of the object.

Recapitulation.—In this section we have considered the Nature and Laws of Reflection; Diffused and Invisible light; the Apparent Direction of bodies; Images formed in Plane Mirrors and their Construction; Concave Mirrors, their Effects, Principal and Conjugate Foci; Images formed by them with their Construction, Projection and Description; foci and images for Convex Mirrors.

SECTION III.

REFRACTION OF LIGHT.

611. Preparatory.—So far, we have considered only that part of the incident beam that is turned back from the reflecting surface. As a general thing, a part of the beam enters the reflecting substance, being rapidly absorbed when the substance is opaque and freely transmitted when the substance is transparent. We have now to consider those rays that enter a transparent substance.

(*a.*) Procure a clear glass bottle with flat sides, about 4 inches (10 *cm.*) broad. On one side paste a piece of paper, in which a circular hole has been cut. On this clear circular space, draw two ink-marks at right angles to each other, as shown in Fig. 292. Fill the bottle with clear water up to the level of the horizontal ink-mark. Hold it so that a horizontal sunbeam from the heliostat may pass through the clear sides of the bottle above the water, and notice that the beam passes through the bottle in a straight line. Raise the bottle so that the beam shall pass through the water, and notice that the beam is still straight. In a card, cut a slit about 5 *cm.* long and 1 *mm.* wide. Place the card against the bottle as shown in the figure. Reflect the beam through this slit so that it

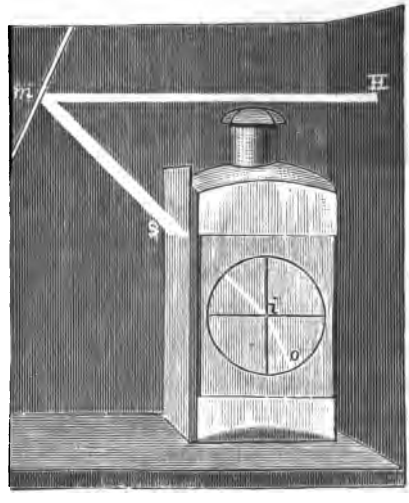


FIG. 292.

shall fall upon the surface of the water at *i*, the intersection of the two ink-marks. Notice that the reflected beam is straight until it reaches the water, but that it is bent as it obliquely enters the water.

612. Refraction.—*Refraction of light is the bending of a luminous ray when it passes from one medium to another.*

613. Index of Refraction.—If a ray of light from *L* (Fig. 293) fall upon the surface of water at *A*, it will be refracted as shown in the figure. The angle *LAB* is the angle of incidence and *KAC* the angle of refraction, *BC* being perpendicular to the water's surface. From *A* as a centre, with a radius equal to unity, describe a circle. From the points *m* and *p*, where this circle cuts the incident and refracted rays, draw *mn* and *pq* perpendicular to *BC*. Then will *mn* be the sine of the angle of incidence and *pq* the sine of the angle of refraction. *The quotient arising from dividing the sine of the angle of incidence by the sine of the angle of refraction is called the index of refraction for the two media.* It is evident that the greater the refractive power of the substance, the less the value of the divisor *pq*, and the greater the value of the quotient, the index of refraction.

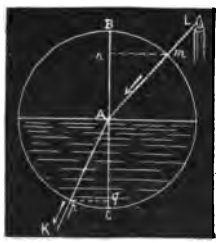


FIG. 293.

(*a*.) The following table gives the indices of refraction when light passes from a vacuum into any of the substances named :

Air	1.000294	Flint glass	1.575
Water	1.336	Carbon bisulphide	1.678
Alcohol	1.374	Diamond	2.439
Crown glass	1.534	Lead chromate	2.974

The index of refraction for any two media may be found by dividing the absolute index of one, as given above, by the absolute index of the other.

614. Laws of Refraction of Light. — (1.) *When light passes perpendicularly from one medium to another it is not refracted.*

(2.) *When light passes obliquely from a rarer to a denser medium* it is refracted toward a line drawn, at the point of incidence, perpendicular to the refracting surface, or, more briefly, *it is refracted toward the perpendicular.*

(3.) *When light passes obliquely from a denser to a rarer medium, it is refracted from the perpendicular.*

(4.) The incident and refracted rays are in the same plane which is perpendicular to the refracting surface.

(5.) The index of refraction is constant for the same two media.

615. Illustrations of Refraction.—Put a small coin into a tin cup and place the cup so that its edge just intercepts the view of the coin. A ray of light coming from the coin toward the observer must pass above his eye and thus be lost to sight. If, now, water be gradually poured into the cup, the coin will become visible. The rays are bent down as they emerge from the water and some of them enter the eye. For the same reason, an oar or other stick half immersed in water seems bent at the water's surface, while rivers and ponds whose bottoms

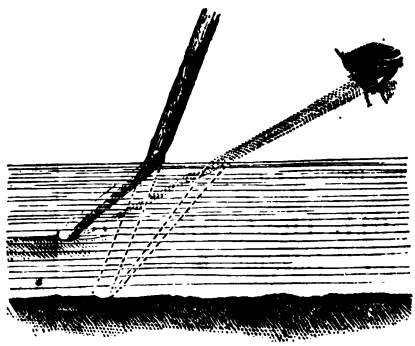


FIG. 294.

are visible are generally deeper than they seem to be. (Fig. 294.) As air expands, its index of refraction becomes less. Hence the indistinctness and apparent unsteadiness of objects seen through air rising from the surface of a hot stove. Light is refracted as it enters the earth's atmosphere. Hence the heavenly bodies appear to be further above the horizon than they really are except when they are overhead.

616. Total Reflection. — When a ray of light passes from a rarer into a denser medium, it may always approach the perpendicular so as to make the angle of refraction less than the angle of incidence (§ 614 [2]). But when a ray of light attempts to pass from a denser into a rarer medium there are conditions under which the angle of refraction cannot be greater than the angle of incidence. *Under such circumstances the ray cannot emerge from the denser medium, but will be wholly reflected at the point of incidence.* Fig. 295 represents luminous rays emitted from *A*, under water, and seeking a passage into air. Passing from the perpendicular, the angle of refraction increases more rapidly than the angle of incidence until one ray is found that emerges and grazes the surface of the water. Rays beyond this cannot emerge at all.

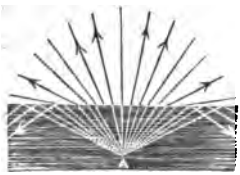


FIG. 295.

617. The Critical Angle. — Imagine a spherical (Florence) flask half filled with water. A ray of light from *L* will be refracted at *A* in the direction of *R*. If the angle of incidence, *CAL*, be

FIG. 296.

gradually increased the angle of refraction will be gradually increased until it becomes 90°, when the ray will graze the surface of the water *AM*. If the source of light be still further removed from *C*, as to *l*, the ray will be reflected to *r* (§ 591). For all media there is an incident angle of this kind, called the critical or limiting angle, beyond which *total internal reflection* will take the place of refraction. The reflection is called total because all of the incident light is reflected, which is never the case in ordinary reflection. Hence, a surface at which total reflection takes place constitutes the most perfect mirror possible. The critical angle (with reference to air) is 48° 35′ for water; 40° 49′ for glass; 23° 43′ for diamond.

(*a*.) From this it follows, as may be seen by referring to Fig. 295, that to an eye placed under water, all visible objects above the water would appear within an angle of 97° 10′, or twice the critical angle for water.

(*b*.) The phenomena of total reflection may be produced by placing the bottle shown in Fig. 292 upon several books resting upon a table, and inverting the card so that a beam of light reflected obliquely upward from a mirror on the table may enter through the slit near the bottom of the bottle, taking a direction through the water similar to the line *lA* of Fig. 296. When one looks into an aquarium in a direction similar to *rA*, *images* of fish or turtles near the surface of the water are often seen.

(*c*.) Place a strip of printed paper in a test-tube; hold it obliquely in a tumbler of water and look downward at the printing which will be plainly visible. Change the tube gradually to a vertical position, and soon the part of the tube in the water takes a silvered appearance and the printing becomes invisible. Show that, in this case, the disappearance of the reading is due to total reflection. By dissolving a small bit of potassium bichromate in the water, the tube will have a golden instead of a silver-like appearance.

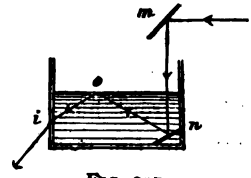


FIG. 297.

(*d*.) Fig. 297 represents a glass vessel partly filled with water. Mirrors are

placed at *m* and *n*. In this way a ray may be reflected at *m*, *n* and *a*, and refracted at *i*.

(*e*.) Fig. 298 represents a glass jar with an opening, from which a stream of water issues under a head (§ 254 [*a*]) kept constant. Through a lens placed opposite this orifice, a concentrated beam of light from the heliostat is thrown into the stream of water as it issues. Internal reflection keeps most of it there, a prisoner. The stream of water is full of light and appears a stream of melted metal. Thrust a finger into the stream and notice the effect. Place a piece of red glass between the heliostat and the lens; the water looks like blood. Thrust the finger into the stream again. Repeat the experiment with pieces of glass of other colors in place of the red.

FIG. 298.

618. Refraction Explained.—To understand the way in which a ray of light is refracted, let us consider its passage through a glass prism, *ABC*. It must be understood that *the velocity of light is less in glass than in air, and that the direction in which a wave moves is perpendicular to its wave front.* A wave in the ether approaches the surface of the prism *AB*. When at *a*, the lower end of the wave front first strikes the glass and enters it. The progress of this end of the wave front, being slower than that of the other which is still in the air, is continually retarded until the whole front has entered the glass. The wave front thus assumes the position shown at *c*. But the path of the wave being perpendicular to the front of the wave, this

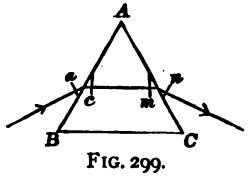


FIG. 299.

change of front causes a change in the direction of the ray which is thus *refracted toward* a perpendicular. The wave now moves forward in a straight line until the top of the wave front strikes AC, the surface of the prism, as shown at m. The upper end of the wave front emerging first into the air gains upon the other end of the front which is still moving more slowly in the glass. When the lower end emerges from the glass, the wave has the position shown at n. This second change of front involves another change in the direction of the ray which is now *refracted from* the perpendicular.

619. Three Kinds of Refractors.—When a ray of light passes through a refracting medium, three cases may arise:

(1.) When the refractor is bounded by planes, the refracting surfaces being parallel.

(2.) When the refractor is bounded by planes, the refracting surfaces being not parallel. The refractor is then called a prism.

(3.) When the refractor is bounded by two surfaces of which at least one is curved. The refractor is then called a lens.

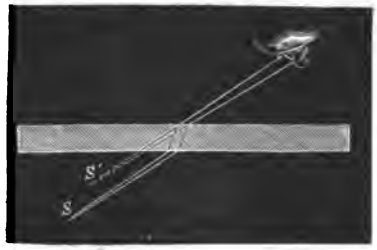


FIG. 300.

620. Parallel Plates.—When a ray passes through a medium bounded by parallel planes the refractions at the two surfaces are equal and contrary in direction. The direction of the ray after passing through the plate is

parallel to its direction before entering; the ray merely suffers *lateral* aberration. Objects seen obliquely through such plates appear slightly displaced from their true position.

621. Prisms.—A prism produces two simultaneous effects upon light passing through it; a change of direction and decomposition. The second of these effects will be considered under the head of dispersion (§ 636).

(*a.*) Let *mno* represent a section formed by cutting a prism by a plane perpendicular to its edges. A ray of light from *L* being refracted at *a* and *b* enters the eye in the direction *bc*. The object being seen in the direction of the ray as it enters the eye (§ 594), appears to be at *r*. An object seen through a prism seems to be moved in the direction of the edge that separates the refracting surfaces. The rays themselves are bent toward the side that separates the refracting surfaces, or toward the thickest part of the prism.

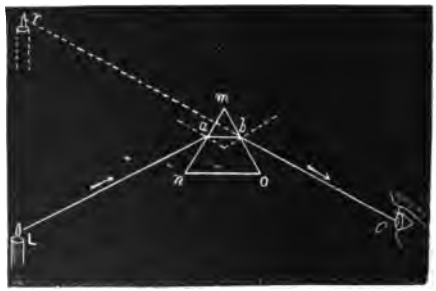


FIG. 301.

(*b.*) Prisms are generally made of glass, their principal sections being equilateral triangles. In order to give a liquid the form of a prism, it is placed in a vessel (Fig. 302) in which at least two sides are glass plates not parallel. Bottles are made for this purpose.

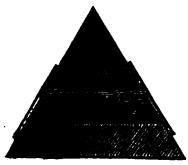


FIG. 302.

(*c.*) In Fig. 303, *ABC* is the principal section of a right-angled isosceles, glass prism, right-angled at *C*. A ray of light falling perpendicularly upon either of the cathetal (*cathetus*) surfaces, as *AC*, will not be refracted. With *AB*, it will make an angle of 45° which exceeds the critical angle for glass (§ 617). It will therefore be totally reflected and pass without refraction from the cathetal surface *BC*. Such prisms are often used in optics instead of mirrors.

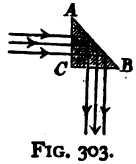


FIG. 303.

622. Lenses.—Lenses are generally made of crown glass which is free from lead, or of flint glass which contains lead and has greater refractive power. The curved surfaces are generally spherical. With respect to their shape, lenses are of six kinds:

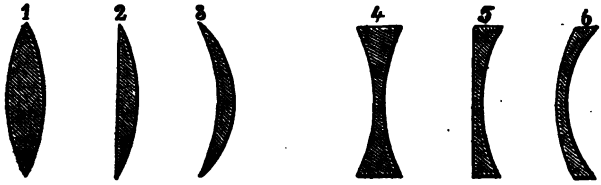


FIG. 304.

(1.) Double-convex,
(2.) Plano-convex,
(3.) Concavo-convex, or meniscus,
} Thicker at the middle than at the edges.

The double-convex may be taken as the type of these.

(4.) Double-concave,
(5.) Plano-concave,
(6.) Convex-concave, or diverging meniscus,
} Thinner at the middle than at the edges.

The double-concave may be taken as the type of these.

(*a.*) The effect of convex lenses may be considered as produced by two prisms with their bases in contact; that of concave lenses, by two prisms with their edges in contact.

623. Centre of Curvature; Principal Axis; Optical Centre.—A double-convex lens may be described as the part common to two spheres which intersect each other. The centres of these spheres are the centres of curvature of the lens. The straight line passing through the centres of curvature is the principal axis of the lens. In every lens there is a point on the principal axis called the optical centre. When the lens is bounded by spherical surfaces of equal curvature, as is generally the case, the optical centre is at equal distances from the two

faces of the lens. Any straight line, other than the principal axis, passing through the optical centre is a secondary axis.

(*a.*) If a ray of light passing through the optical centre be refracted at all, the two refractions will be equal and opposite in direction. The slight lateral aberration thus produced may be disregarded.

624. Principal Focus.—*All rays parallel to the principal axis will, after two refractions, converge at a point called the principal focus.* This point may lie on either side of the lens, according to the direction in which the light moves; it is a real focus. The greater the refracting power of the substance of which the

FIG. 305.

lens is made, the nearer the principal focus will be to the lens. In a double-convex lens of crown glass, the principal focal distance is equal to the radius of curvature; in a plano-convex lens of the same material, it is twice as great.

(*a.*) The position of the principal focus of a lens is easily determined. Hold the lens facing the sun. The parallel solar rays incident upon the lens will converge at the principal focus. Find this point by moving a sheet of paper back and forth behind the lens until the bright spot formed upon the paper is brightest and smallest.

(*b.*) It is also true that rays diverging from a point at twice the principal focal distance from the lens will converge at a point just as far distant on the other side of the lens. Rays diverging from f will converge at f', these two points being at twice the focal distance from the lens. By experimenting with a lens and candle-flame until the flame and its image are at equal distances from the lens, we are able, in a second way, to determine the principal focal distance of the lens. The conjugate foci situated at twice the principal focal distance are called *secondary foci*.

625. Conjugate Foci.—Rays diverging from a luminous point in the principal axis at a small distance beyond the principal focus on either side of the lens will form a focus on the principal axis beyond the other principal focus. Thus, rays from L will converge at l; conversely, rays from l will converge at L (§ 602). If the luminous point be in a secondary axis, the rays will converge to a point in the same secondary axis. *Two*

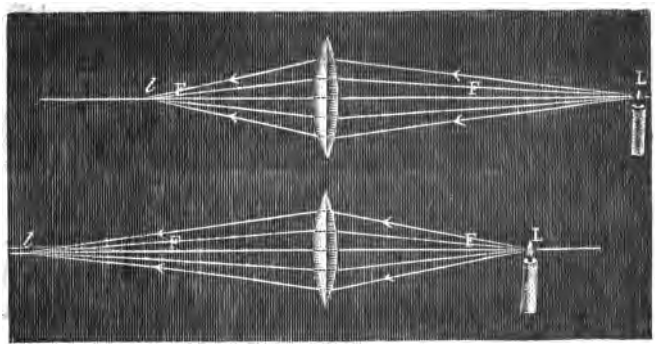


FIG. 306.

points thus related to each other are called conjugate foci; the line joining them always passes through the optical centre.

(*a.*) If the luminous point be more than twice the focal distance from the lens, the conjugate focus will lie on the other side of the lens at a distance greater than the focal distance, but less than twice the focal distance. If the luminous point be moved toward the lens, the focus will recede from the lens. When the luminous point is at one secondary focus, the rays will converge at the other secondary focus. When the luminous point is between the secondary and principal foci, the rays will converge beyond the secondary focus on the other side of the lens. When the luminous point is at the focal distance, the emergent rays will be parallel and no focus will be formed. When the luminous point is at less than the focal distance, the emergent rays will still diverge as if from a point on the same side of the lens, more distant than the principal focus.

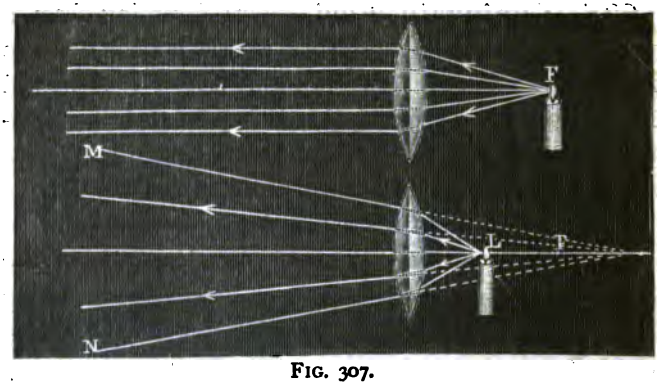


FIG. 307.

This focus will be virtual. Conversely, converging rays falling upon a convex lens will form a focus nearer the lens than the principal focus. (See Fig. 307.)

626. Conjugate Foci of Concave Lens.— Rays from a luminous point at any distance whatever will be made more divergent by passing through a concave lens.

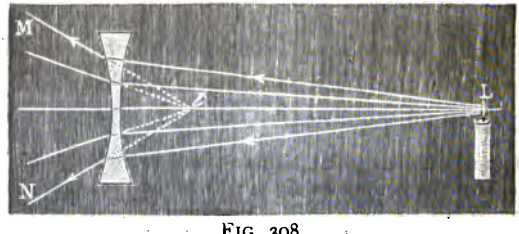


FIG. 308.

Rays parallel to the principal axis will diverge after refraction as if they proceeded from the principal focus. In any case, the focus will be virtual, and nearer the lens than the luminous point.

627. Images Formed by Convex Lenses.— The analogies between the convex lens and the concave

mirror cannot have escaped the notice of the thoughtful pupil. Others will appear. If secondary axes be nearly parallel to the principal axis, well-defined foci may be formed upon them, as well as upon the principal axis. A number of these foci may determine the position of an image formed by a lens.

(*a*.) The linear dimensions of object and image are directly as their respective distances from the centre of the lens; they will be virtual or real, erect or inverted, according as they are on the same side of the lens or on opposite sides.

628. Construction for Real Images.—To determine the position of the image of the object *AB* (Fig. 309), draw from any point, as *A*, a line parallel to the principal axis. After refrac-

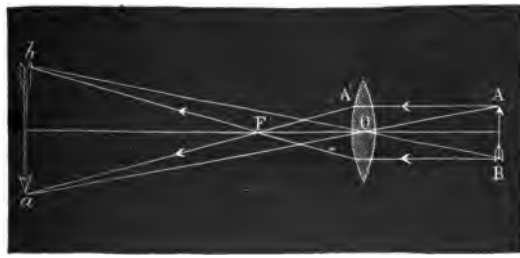


FIG. 309.

tion, the ray represented by this line will pass through *F*, the principal focus. Draw the secondary axis for the point *A*. The intersection of these two lines at *a* determines the position of the conjugate focus of *A*. In similar manner, the conjugate focus of *B* is found to be at *b*. Joining these points, the line *ab* is the image of the line *AB*.

629. Diminished Real Image.—If the object be more than twice the focal distance from the convex lens, its image will be real, smaller than the object and inverted (Fig. 310). Construct the image as indicated in the last paragraph.

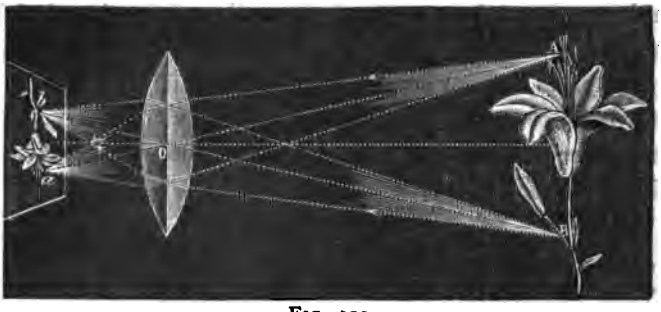


FIG. 310.

630. Magnified Real Image.—If the object be further from the lens than the principal focus, but at a

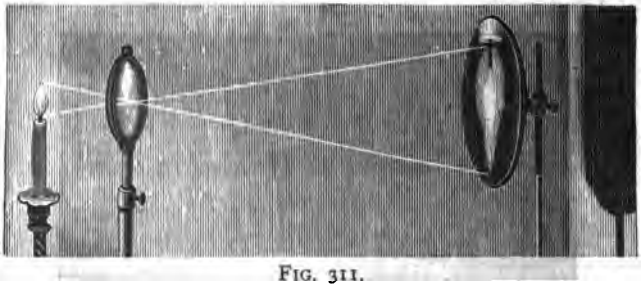


FIG. 311.

distance less than twice the focal distance, the image will be real, magnified and inverted. (Fig. 311.) Construct the image.

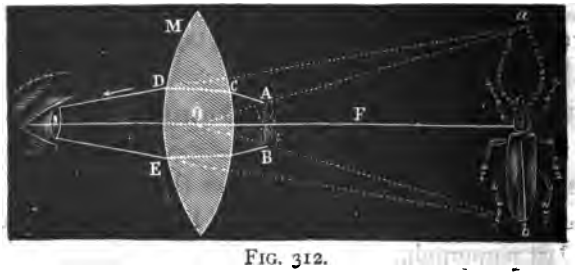


FIG. 312.

631. Virtual Image.—If the object be placed nearer the lens than the principal focus, the image will be virtual, magnified and erect. (Fig. 312.) This explains the familiar magnifying effects of convex lenses. Construct the image.

632. Image of Concave Lens.—Images formed by a concave lens are virtual, smaller than the object and erect. The construction of the image is shown in Fig. 313.

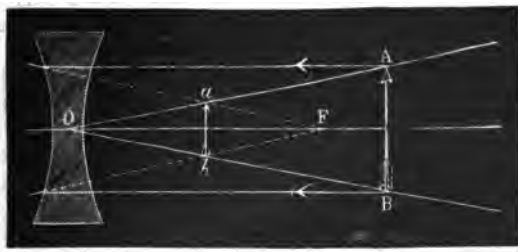


FIG. 313.

Note.—The power of the convex lens to form real and diminished images of distant objects and magnified images of near objects, is of frequent application in such optical instruments as the microscope, telescope, magic lantern, lighthouse lamps, etc. Owing to the identity between heat and luminous rays, a convex lens is also a "burning-glass."

633. Spherical Aberration.—The rays that pass through a spherical lens near its edge are more refracted than those that pass nearer the centre. They, therefore, converge nearer the lens. A spherical lens cannot refract *all* of the incident rays to the same point. Hence "spherical aberration" and its annoying consequences in the construction and use of optical apparatus.

Exercises.

1. (*a.*) What is refraction of light? (*b.*) State the laws governing the same, and (*c.*) give an illustrative diagram.

2. (*a.*) Name and illustrate by diagram the different classes of lenses. (*b.*) Explain, with diagram, the action of the burning-glass.

3. (*a.*) Explain the cause of total reflection. (*b.*) Show, with diagram, how the secondary axes of a lens mark the limits of the image.

4. (*a.*) Using a convex lens, what must be the position of an object in order that its image shall be real, magnified, and inverted? (*b.*) Same, using a concave lens?

5. (*a.*) Show how a ray of light may be bent at a right angle by a glass prism. (*b.*) The focal distance of a convex lens being 6 inches, determine the position of the conjugate focus of a point 12 inches from the lens. (*c.*) 18 inches from the lens.

6. (*a.*) The focal distance of a convex lens is 30 *cm.* Find the conjugate focus for a point 15 *cm.* from the lens. (*b.*) How may the focal length of a lens be determined experimentally?

7. If an object be placed at twice the focal distance of a concave lens, how will the length of the image compare with the length of the object?

8. A small object is 12 inches from a lens; the image is 24 inches from the lens and on the opposite side. Determine (by construction) the focal distance of the lens.

9. A candle flame is 6 feet from a wall; a lens is between the flame and the wall, 5 feet from the latter. A distinct image of the flame is formed upon the wall. (*a.*) In what other position may the lens be placed, that a distinct image may be formed upon the wall? (*b.*) How will the lengths of the images compare?

Recapitulation.—In this section we have considered the Definition, Index, Laws and Explanation of refraction; Internal Reflection; Plates, Prisms and Lenses; principal and conjugate Foci of lenses; Construction for conjugate foci and images; Spherical Aberration.

SECTION IV.

CHROMATICS—SPECTRA.

634. Other Results of Refraction.—In our previous consideration of luminous rays we have studied the effect of reflection and refraction upon the *direction* of rays; in fact, we have dealt with only those properties which are common to all luminous rays. But the properties of light and the phenomena of refraction are not so simple as we might thus be led to suppose. Most luminous objects emit light of several kinds blended together. We must not be satisfied with our knowledge of light until we are able to sift these varieties one from the other, and to deal with any one kind by itself.

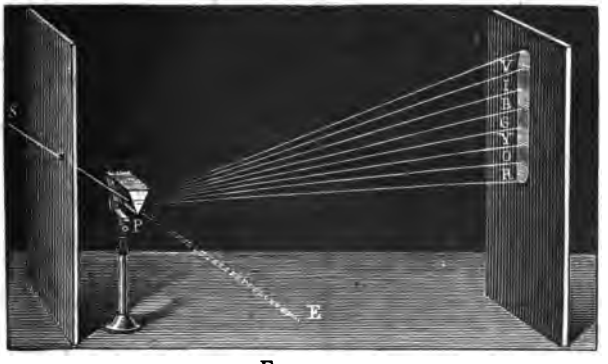


FIG. 314.

635. Solar Spectrum.—Admit a sunbeam through a very small opening in the shutter of a darkened room. The opening may be prepared by cutting a slit an inch (25 *mm.*) long and $\frac{1}{25}$ of an inch (1 *mm.*) wide in a card. See that the edges of the slit are smooth. Tack the slit over a larger opening in the shutter. If we look at the aperture from *E* we shall see the sun beyond. The path of the beam from *S* to *E* is made visible by the floating

dust. If a prism be placed in the path of the beam, as shown in Fig. 314, the sides of the slit and edges of the prism being horizontal, the beam will be refracted upward. If the refracted beam be caught upon a screen, it will appear as a band of differently colored light, passing by imperceptible gradations from red at the bottom, through orange, yellow, green, blue and indigo to violet at the upper end of the beautifully colored band. *This colored band is called the solar spectrum.*

(*a.*) The different colors do not occupy equal space in the spectrum, orange having the least and violet the most. The initials of these colors form the meaningless word VIBGYOR, which may aid the memory in remembering these prismatic colors in their proper order. By placing the slit in a vertical position, and standing the prism on its end so that its edges will be parallel with the sides of the slit, the spectrum will be projected as a horizontal band.

636. Dispersion.—By looking at Fig. 314, it will be seen that the red rays have been refracted the least and the violet the most of all the luminous rays. *This separation of the differently colored rays by the prism is called the dispersion of light;* it depends upon the fact that rays of different colors are refracted in different degrees.

637. Pure Spectrum.—The spectrum above described is composed of overlapping and differently-colored images of the slit. In a pure spectrum these images must not overlap. The first requisite in preventing this overlapping is that the slit be very narrow.

(*a.*) The most simple way of producing a pure spectrum is to look through a prism at a very narrow slit in the shutter of a darkened room. The edges of the prism should be parallel to the slit; the prism should be at least five feet (1½ *m.*) from the slit; the prism should be turned until the colored image of the slit is at the least

angular distance from the slit itself. A pure spectrum is also obtained by passing the beam through several prisms in succession, thus increasing the dispersion.

638. Fraunhofer's Lines.—A pure solar spectrum is not continuous, but is crossed by numerous dark lines, many hundreds of which have been counted and accurately mapped. The more conspicuous of these dark lines are distinguished by letters of the alphabet, as shown in Fig. 315. Each of these dark lines indicates that a particular kind of ray is wanting in solar light.

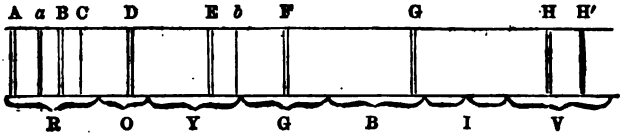


FIG. 315.

(*a.*) The spectra of incandescent solids are continuous, from the extreme red to a limit depending upon the temperature. The spectra of incandescent gases (not containing solid particles in suspension) are non-continuous, consisting of a number of definite bright lines. A candle or gas flame gives a continuous spectrum because it is chiefly due to the incandescence of solid carbon particles.

(*b.*) The spectroscope is an instrument for producing and observing pure spectra. It has proved to be one of the most powerful aids to modern science. It affords the most delicate means of chemical analysis; by its aid several elements have been discovered; the presence of $\frac{1}{1000000}$ of a grain of sodium has been detected by "spectrum analysis." It is of incalculable importance to the astronomer. For definite information, the pupil is necessarily referred to some of the excellent manuals upon the subject recently published.

639. Synthesis of White Light.—By analysis, we have shown that white light is composed of seven primary colors. The same fact may be shown synthetically, for by recombining these spectrum colors white light will be produced.

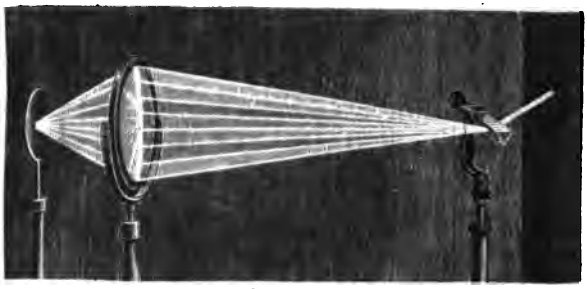


FIG. 316.

(*a*.) This recombination may be effected by means of a convex lens (Fig. 316) or a concave mirror. Another simple method of recombination is afforded by "Newton's disc" (Fig. 317), which contains the prismatic colors in proper proportion. When this disc is rapidly revolved by means of the whirling table (see Fig. 7), or by fastening it to a large top, the colors are blended and the disc appears grayish white. Still another way of producing this recomposition is to pass the light as it emerges from the first prism through a second prism, placed in a position inverted with reference to the first.

FIG. 317.

640. Color of Bodies.—The color of a body is its property of reflecting or transmitting to the eye light of that particular color, the other rays being absorbed. This power may be described as selective absorption.

(*a*.) Properly speaking, color is not a property of matter, but of light. A ribbon is called red, but the redness belongs to the light, not to the ribbon. There would be more propriety in saying that the ribbon has *all the other colors* of the rainbow, because it absorbs the others and reflects the red. If the red ribbon be placed in the green or blue of the spectrum it will appear black because it receives no red rays to reflect. Colored substances decompose the incident light, absorbing some rays and assuming the hue of those they reflect or transmit to the eye. A body that absorbs very few of the rays is white; one that absorbs nearly all is black. Therefore, black is not a color but its absence.

(*b.*) Paint three narrow strips of cardboard, one vermilion red, one emerald green, and the other aniline violet. Be sure that the coats are thick enough thoroughly to hide the cardboard. When dry, hold the red strip in the red of the solar spectrum; it appears red. Move it slowly through the orange and yellow; it grows gradually darker. In the green and colors beyond, it appears black. Repeat the experiment with the other two strips, and carefully notice that the effects are in accordance with the principle above stated.

641. The Rainbow.—The rainbow is due to refraction, reflection and dispersion of sunlight by waterdrops. The necessary conditions are:

(1.) A shower during sunshine.

(2.) That the observer shall stand with his back to the sun, between the falling drops and the sun.

(*a.*) The centre of the circle of which the rainbow forms a part is in the prolongation of a line drawn from the sun through the eye of the observer. *This line is called the axis of the bow.*

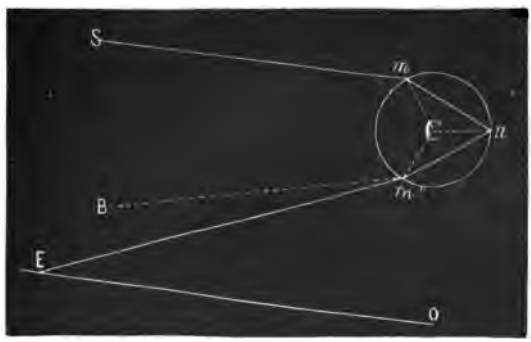


FIG. 318.

642. Dispersion by a Raindrop.—Suppose the circle whose centre is at *C* (Fig. 318) to represent the section of a raindrop. A ray of sunlight, as *Sm*, falling upon the raindrop would be refracted at *m*, reflected at *n*, and again

refracted at m'. In passing thus through the drop, the light is also decomposed. If $m'E$ represent the path of a red ray, the violet ray will traverse a path above, because violet is refracted more than red. The path of this violet ray may be represented by $m'B$. If the raindrop be in the exact position for the red ray, $m'E$, to enter the eye of the observer, the violet and other colored rays will pass overhead and not be seen. This drop will appear red.

643. Successive Colors of the Rainbow.—In order that a violet ray may enter the eye at E, it must proceed from a drop situated *below* the one that sends the red ray. This drop will appear violet. Intervening drops will give the intervening colors of the solar spectrum in their proper order as is shown in Fig. 319. Owing to the distance of the sun, all of the incident rays are parallel with the axis EO, drawn from the sun through E, the eye of the observer, to O, the centre of the circle of which the bow forms a part. The angle between the incident and the emergent ray, SRE, and consequently the angle REO, is, for the red ray, about 42°. The angles $S'VE$ and VEO are, for the violet ray, about 40°. The other colors lying between these, it will be seen that the angular width of the rainbow is about two degrees.

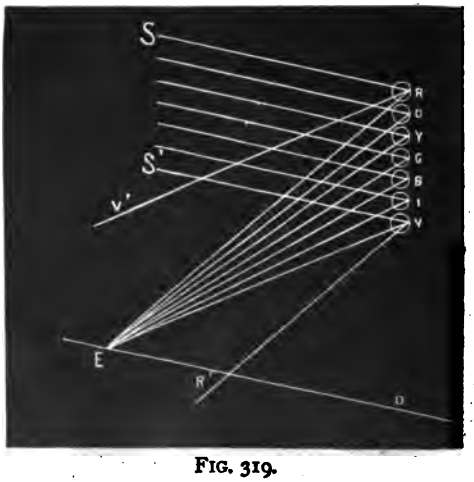


FIG. 319.

644. Form and Extent of the Rainbow.—From Fig. 320, it will be seen that every drop in the arc of

a circumference drawn, with O as a centre and with OV as radius, being opposite the sun and having the same angular distance from OE, viz., 40°, will send violet colored rays to the eye at E, and the violet colored part of the bow will be a circular arch. For the same reason, the red of the bow is a circular arch lying without the violet and at an angular distance of two degrees therefrom; the other colors will form circular arches lying between these two. If the sun be at the horizon, EO will be horizontal and the arches will be semicircles. If the sun be above the horizon, O will be depressed below the horizon and less than semicircles will be seen. If the observer be on a mountain-top or up in a balloon, he may see more than a semicircle.

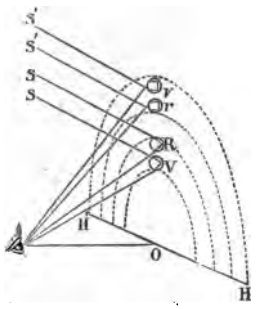


FIG. 320.

645. The Secondary Bow.—Sometimes two colored arches are seen, one within the other. The inner which we have just considered is called the primary bow; the outer, the secondary bow.

(*a.*) In explaining the primary bow we traced a ray of light falling upon the top of the raindrop; to explain the secondary bow we trace a ray falling upon its lower part. Such a ray, as Sm, will be refracted at m, reflected at n and n', and again refracted at m', coming to the eye at E. If the ray which thus comes to the eye at E be a red ray, the violet will follow $m'V$, and thus, passing below the eye because of its greater refrangibility, be lost to sight. The drop that sends a violet ray to the eye at E must be placed *above instead of below* the drop that sends the red ray. (Fig. 321.)

(*b.*) In the secondary bow, the red arch will be on the inside, with an angular distance from the axis EO of about 51°, while the violet will be on the outside at an angular distance of about 54°. In the

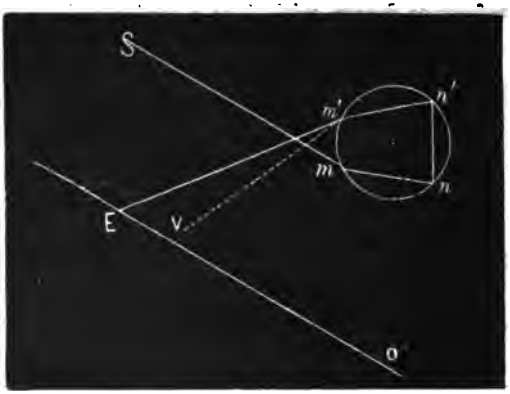


FIG. 321.

case of either bow some light is lost at each reflection; therefore, since there are more reflections in the secondary bow, this will appear fainter.

646. Chromatic Aberration.—It is impossible, by means of a single spherical convex lens, to bring all of the incident rays to a common focus. The blue and violet rays being refracted more than the red rays will converge at points nearer the lens. In consequence of this, when an image is projected upon a screen, the image is surrounded with a colored border, the color depending upon the distance of the screen from the lens. *This inability of a single lens to bring differently colored rays to the same focus is called chromatic aberration.*

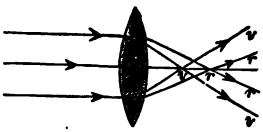


FIG. 322.

647. Achromatic Lens.—A convex lens of crown glass, by combination with a concave lens of flint glass, may have its dispersive power neutralized without completely

neutralizing its refraction. As the converging effect of the compound lens is not destroyed, images may be formed; as the dispersive effect is destroyed, the colored fringe is avoided. *A combination of lenses by which dispersion is avoided and refraction secured is called an achromatic lens.*

648. Properties of the Spectrum.—We have seen that we may decompose a sunbeam by availing ourselves of the varying refrangibility of the different kinds of rays of which it is composed. We have been able in this manner to produce the seven primary colors from white light. But our analytic investigations must go still further. Beyond the limits of the *visible* spectrum, in both directions, there are rays that do not excite the optic nerve, the existence of which, however, may be easily proved. The spectrum has three properties which we must consider in detail: luminous, thermal and actinic.

649. Luminous Spectrum.—We have seen the difference of rays in different parts of the spectrum in regard to color, but they also differ in respect to intensity or illuminating power. An object, as a printed page, will be illuminated more strongly, and therefore seen more distinctly, when placed in the yellow than when placed in the red or violet part of the spectrum.

(*a*.) The difference in color between the rays found in different parts of the spectrum is merely one of rate of vibration or wave-length. The intensity of the light found at any particular part of the spectrum depends upon the amplitude of vibration. In respect to the visible spectrum, it may be said that brightness is to light what loudness is to sound (§ 431), that color is to light what pitch is to sound (§ 434).

(*b*.) The length of an ether-wave that can awaken the sensation of redness is about $\frac{1}{33000}$ of an inch; of that which can awaken the sensation of violet, about $\frac{1}{57000}$. The waves corresponding to the intermediate colors have intermediate lengths.

650. Thermal Spectrum.—If a very delicate thermometer or thermopile be successively placed in vari-

ous parts of the spectrum it will be found that the temperature is scarcely affected in the violet, but that there is a continual increase in temperature as the thermometer is moved toward the other end of the spectrum, it being quite marked in the red. The greatest augmentation of temperature takes place beyond the red, wholly outside the visible spectrum. *We thus detect ultra-red rays constituting a heat spectrum.* Their position indicates their low refrangibility and increased wave-length. Because of its diathermancy, a rock-salt prism is desirable for this experiment; glass absorbs most of the ultra-red rays.

651. Actinic Spectrum.—The actinic or chemical effects of sunlight are, in a general way, familiar to all. For example, plants absorb carbon from the atmosphere only during the day time. Silver chloride is very sensitive to this action of sunlight. The sensitive paper of the photographer will remain unchanged in the dark; it will be quickly blackened in the light. If a piece of paper freshly washed in a solution of sulphate of quinine, or some other fluorescent substance, be held in the ultra-violet rays, it will become visible. Such a slip of paper may be used as a test for the presence of actinic rays. By placing it successively in the different parts of the visible spectrum, it will be affected least in the red and most in the violet. The maximum actinic effect will be found at a point beyond the violet, wholly outside the visible spectrum. *We thus detect ultra-violet rays constituting an actinic spectrum.* Their position indicates their high refrangibility; that their wave-length is less than that of the violet rays. A quartz prism is desirable for this experiment as glass quenches most of the actinic rays.

652. Curves of Intensity.—Fig. 323 represents, by means of curves, the relative intensities of these three properties of the solar spectrum produced by a flint-glass prism. The wave-length will determine the position of the ray in the horizontal band. The rays that have the greatest heating effect are those whose particular wave-length place them just beyond the red rays; the highest point of the thermal curve is over this part of the spectrum. The rays that have the greatest illuminating effect are those whose particular wave-length place them a little at the right of *D* (§ 638); the highest point of the luminous curve is over this point. The rays of greatest actinic effect are similarly indicated. If a rock-salt or a quartz prism be used, the curves will be somewhat different from those here shown. All of the luminous rays are, to a certain extent, heat rays; some of the heat rays are not luminous. Every luminous ray

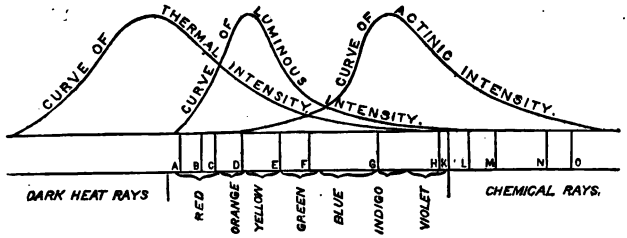


FIG. 323.

has the power of exciting to action two sets of nerves; dark heat rays, only one. The same rays may arouse the sensation of light by acting upon the optic nerve, or the sensation of warmth by action upon the nerves of common sensibility. The name given to the radiant energy depends upon the way in which it is perceived.

653. The Electric Light.—The electric light is particularly rich in these invisible rays. The dark heat rays may be sifted from the beam of light by passing it through a transparent solution of alum; only the luminous rays will be allowed to pass. The luminous rays may be sifted out by sending the beam through an opaque solution of iodine in carbon bi-sulphide. If these solutions be placed in spherical flasks, they will constitute lenses which will refract the transmitted rays to well defined foci. The focus of the transparent solution will be brilliantly illuminated, but will have little heating power; that of the opaque solution will be invisible, while gun-cotton placed there will be instantly exploded. Platinum-

foil has been raised to a red heat at one of these dark foci. In the spectrum of the electric light, the actinic part is about twice as long as the visible part. The phenomena of fluorescence, which renders these rays visible, is often produced by sending the electric discharge through a Geissler tube (§ 371 [31]) surrounded by a fluorescent solution.

654. Selective Radiation and Absorption.—Radiation of light or heat consists in giving motion to the ether; absorption consists in taking motion from the ether. Molecules of one kind are able to vibrate at one rate; those of another kind may be obliged to vibrate at a different rate. The first set of molecules may be able to give to the ether, or take from it, a rate of vibration which, in the ether, constitutes obscure heat. These molecules can absorb or radiate obscure heat. They may be unable to vibrate at the higher rate which will enable them to absorb or radiate light. They must either transmit or reflect light that falls upon them. In other words, a body absorbs with special energy the kind of rays itself can radiate, both the absorption and the radiation depending upon the possible rate of vibration of the molecules of the body.

(*a*.) In the case of gases, the period of molecular vibration is sharply defined. Gaseous molecules, like musical strings, can vibrate at only definite rates. Liquid and solid molecules, like sounding-boards, are able to vibrate at different rates lying between certain fixed limits. These limits depend largely upon the temperature. This principle underlies solar, spectrum analysis.

655. Relation between Radiation and Absorption.—Transparent bodies *are* transparent because the ether-waves which produce or constitute light pass between the molecules of such bodies without having their wave-motion transferred to the molecules. Diathermanous bodies transmit heat freely because the ether-waves which produce or constitute heat pass between the molecules of

such bodies without having their peculiar wave-motion transferred to the molecules of the body through which they pass. When a ray of light or heat, in passing through a substance, gives its energy to the molecules between which it is passing in the ether, the ray is absorbed. It no longer exists as radiant energy; it has become absorbed heat, and warms the body. It is no longer a motion of the ether; it has become a motion of ordinary matter. As in the case of radiant heat, so with light; the best absorbents are the best radiators. A piece of transparent, colorless glass will absorb very little light; heat it intensely, and it will radiate very little light. On the other hand, a piece of opaque glass will absorb a great deal of light; when heated intensely, it will radiate a great deal of light.

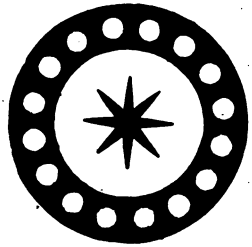


FIG. 324.

(*a.*) If an intensely heated pot of melted lead, tin or plumber's solder be carried into a dark place and the dross skimmed aside by a red-hot iron ladle, the liquid metal (which in sunlight would reflect rather than absorb the light) will appear less bright than the surrounding dross. If a piece of platinum-foil bearing an ink-mark be heated to incandescence and viewed in a dark room, the ink-mark will radiate more light than the metal. Exposed to sunlight, the ink-mark will absorb more light than the metal. If a chalk-mark be made on a black poker, the poker heated red-hot and viewed

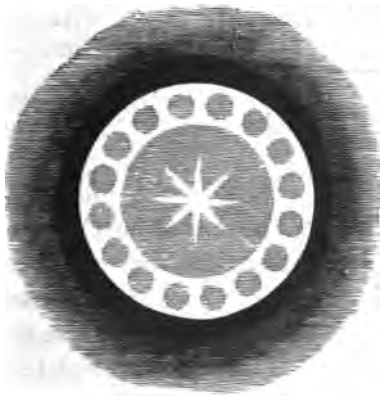


FIG. 325.

in a dark room, the chalk will be less luminous than the iron. If a piece of stone-ware of black and white pattern (Fig. 324) be heated to redness and viewed in a dark room, the black will shine more brightly than the white, the pattern being reversed as shown in Fig. 325.

EXERCISES.

1. Give the best reason you can think of, why the rainbow is a circular arc and not a straight line or of some other shape.
2. Taking the velocity of light to be 188,000 miles per second and the wave-length for green light to be .00002 of an inch, how many waves per second beat upon the retina of an eye exposed to green light?
3. How may spherical and chromatic aberration caused by a lens be corrected?
4. Describe Fraunhofer's lines and tell how they may be produced. Why not through a circular orifice?
5. Describe in full what is meant by dispersion and the dispersive power of a medium.

Recapitulation.—In this section we have considered the Dispersion of light; the Solar Spectrum and Fraunhofer's Lines; the Color of bodies; the Rainbow; Chromatic Aberration and Achromatic Lenses; Luminous, Thermal and Actinic Spectra; the Electric Light; the relation between Radiation and Absorption.

SECTION V.

OPTICAL INSTRUMENTS.—POLARIZATION.

656. Photographers' Camera.—The photographer's camera is nearly the same as the camera-obscura described in § 585. Instead of the darkened room we have a darkened box, *BC*; instead of the simple hole in the shutter, we have an achromatic convex lens, placed in a tube at *A*.

(*a*.) One part of the box, *B*, slides within the other part, *C*. A ground-glass plate is placed in the frame at *E*, which is adjusted so that a well-defined, inverted image of the object in front of *A* is projected upon the glass plate. This adjustment, or "focussing," is completed by moving the lens and its tube by the toothed wheel at *D*. When the "focussing" is satisfactory, *A* is covered with a black cloth, the ground-glass plate replaced by a chemically-prepared sensitive plate, the cloth removed, and the image projected thereon. The light works certain chemical changes where it falls upon this plate, and thus a more lasting image is produced. The preliminary and subsequent processes necessarily involved in photography cannot be considered here; they belong rather to chemistry.

FIG. 326.

657. The Human Eye.—This most admirable of all optical instruments is a nearly spherical ball, capable of being turned considerably in its socket. The outer coat, *S*, is firm, and, excepting in front, is opaque. It is called the "white of the eye," or the sclerotic coat. Its transparent part in front, *C*, is called the cornea. The convexity of the cornea is greater than that of the rest of the eyeball. Behind the cornea is an annular diaphragm, *I*, called the iris. It is colored and opaque; the circular window in its centre is called the pupil. The color of the iris constitutes the color of the eye. Back of the pupil is the crystalline lens, *L*, built of concentric shells of varying density. Its shape is shown in the figure. This lens divides the eye into two chambers, the anterior

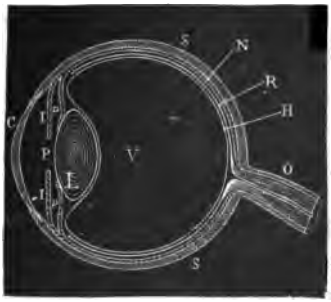


FIG. 327.

chamber containing a limpid liquid called the aqueous humor; the posterior chamber containing a transparent jelly, *V*, called the vitreous humor. The vitreous humor is enclosed in a transparent sack, *H*, called the hyaloid membrane. The cornea, aqueous humor, crystalline lens and vitreous humor are refracting media. Back of the hyaloid membrane is the retina, *R*, an expansion of the optic nerve. Between the retina and the sclerotic coat is *N*, the choroid coat, intensely black and opaque. The eye, optically considered, is simply an arrangement for projecting inverted real images of visible objects upon a screen made of nerve filaments. The image thus formed is the origin of the sensation of vision. If this image be well defined and sufficiently luminous the vision is distinct.

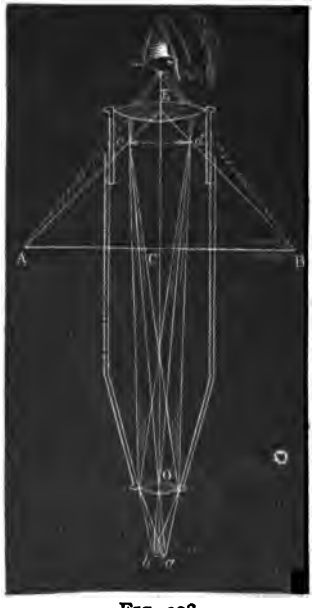


FIG. 328

658. Magnifying-Glasses. — A magnifying-glass, or simple microscope, is a convex lens, generally double-convex. The object is placed between the lens and its principal focus. The image is virtual, erect and magnified (Fig. 312). The visual angle subtended by the image is greater than that subtended by the object (§ 587).

659. Compound Microscope.—The compound microscope consists of two

or more convex lenses placed in a tube. One of these, *o*, called the object-glass or objective, is of short focus. The object, *ab*, being placed slightly beyond the principal focus, a real image, *cd*, magnified and inverted, is formed within the tube (§ 630). The other lens, *E*, called the eye-glass, is so placed that the image formed by the objective lies between the eye-glass and its focus. A magnified virtual image, *AB*, of the real image is formed by the eye-glass (§ 631) and seen by the observer. (See Fig. 328.)

(*a*.) Compound microscopes are usually provided with several objectives of different focal distances, so that a selection may be made according to the magnifying power required. The powers generally used range from 50 to 350 diameters (*i. e.*, they multiply linear dimensions so many times). The object generally needs to be intensely illuminated by a concave mirror or convex lens.

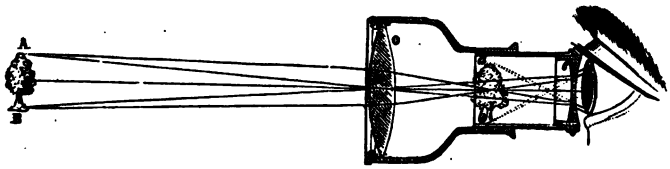


FIG. 329.

660. Galilean Telescope; Opera Glass.—In the telescope attributed to Galileo the objective is a double convex, and the eye-piece a double concave lens. The concave lens intercepts the rays before they have reached the focus of the objective; were it not for this eye-piece, a real, inverted image would be formed back of the position of the concave lens. The rays from *A*, converging after refraction by *O*, are rendered diverging by *C*; they seem to diverge from *a*. In like manner, the image of *B* is formed at *b*. The image *ab* is erect and very near. An opera-glass consists of two Galilean telescopes placed side by side. In a good instrument both lenses are achromatic.

661. Astronomical Telescope; Refractor.—Astronomical telescopes are of two kinds—refractors and reflectors. Fig. 330 represents the arrangement of the lenses and the direction of the rays in the refracting telescope. The object-glass is of large diameter that it

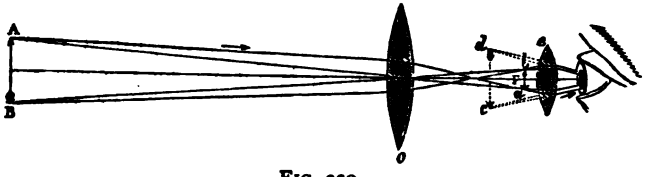


FIG. 330.

may collect many rays for the better illumination of the image. The inverted, real image formed by the objective, *O*, is magnified by the eye-piece, as in the case of the compound microscope. The visible image, *cd*, is a virtual image of *ab*, the real image of *AB*.

662. Reflecting Telescopes.—A reflecting telescope consists of a tube closed at one end by a concave

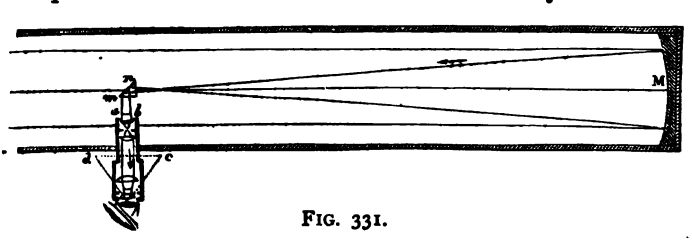


FIG. 331.

mirror, so placed that the image thus formed may be magnified by a convex lens used as an eye-piece. Sometimes the eye-piece consists of a series of convex lenses placed in a horizontal tube, as shown in Fig. 331. The rays from the mirror are reflected by the cathetal prism *mn* (§ 621 [*c*]), and a real image formed at *ab*. This image is

magnified by the glasses of the eye-piece and a virtual image formed at *cd*. The Earl of Rosse built a telescope with a mirror six feet in diameter and having a focal distance of fifty-four feet.

663. Terrestrial Telescope.—The inversion of the image in an astronomical telescope is inconvenient

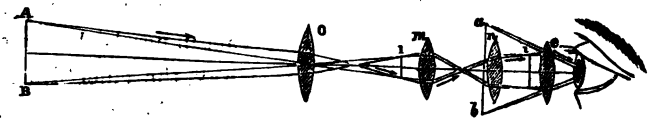


FIG. 332.

when viewing terrestrial objects. This inconvenience is obviated in the terrestrial telescope by the interposition of two double convex lenses, *m*, *n*, between the objective and the eye-piece. The rays, diverging from the inverted image at *I*, cross between *m* and *n*, and form an erect, magnified, virtual image at *ab*.

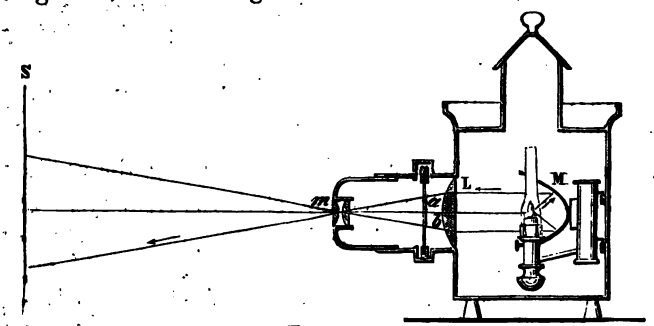


FIG. 333.

664. Magic Lantern.—In the magic lantern, a lamp is placed at the common focus of a convex lens in front of it and of a concave mirror behind it. The light is thus concentrated upon *ab*, a transparent picture, called the "slide." A system of lenses, *m*, is placed at a little

more than its focal distance (§ 630) beyond the slide. A real, inverted, magnified image of the picture is thus projected upon the screen *S*. The tube carrying *m* is adjustable, so that the foci may be made to fall upon the screen and thus render the image distinct. By inverting the slide the image is seen right side up. The solar and electric microscopes act in nearly the same way, the chief difference being in the source of light.

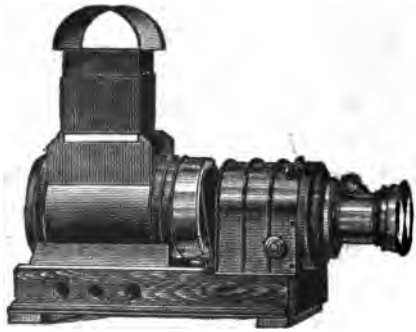


FIG. 334.

(*a.*) **Directions for making a simple magic lantern may be found on page 84 of Mayer and Barnard's little book on *Light*. Fig. 334 represents a very compact and efficient lantern, known as Marcy's Sciopticon, and furnished by Ritchie, of Boston. (See Dolbear's *Art of Projecting*.)**

665. Stereoscopic Pictures.—Close the left eye and hold the right hand so that the forefinger shall hide the other three fingers. Without changing the position of the hand, open the left and close the right eye. The hidden fingers become visible in part. Place a die on the table directly in front of you. Looking at it with only the left eye, three faces are visible, as shown at *A*, Fig. 335. Looking at it with only the right eye, it appears as shown at *B*. From this we see that *when we look at a solid, the images upon the retinas of the two eyes are different.* If in any way we combine two

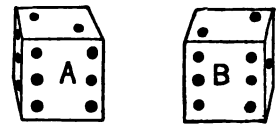


FIG. 335.

drawings, so as to produce images upon the retinas of the two eyes like those produced by the solid object, we obtain the idea of solidity.

FIG. 336.

666. The Stereoscope.—To blend these two pictures is the office of the stereoscope. Its action will be readily understood from Fig. 336. The diaphragm *D* prevents either eye from seeing both pictures at the same time. Rays of light from *B* are refracted by the half-lens *E'* so that they seem to come from *C*. In the same way, rays from *A* are refracted by *E* so that they also seem to come from *C*. The two slightly different pictures thus seeming to be in the same place at the same time are successfully blended, and the picture "stands out," or has the appearance of solidity. If the two pictures of a stereoscopic view were exactly alike, this impression of solidity would not be produced.

667. Polarization.—If a horizontal string, tightly drawn, be hit a vertical blow, a wave will be formed with vibrations in a vertical plane. If the string be hit a horizontal blow, a wave will be formed with vibrations in a horizontal plane. Thus a transversal wave is capable of assuming a particular side or direction while a longitudinal wave is not. This is expressed by saying that a transversal wave is capable of polarization. Polarization of light may be produced in three ways—by absorption, by reflection and by double refraction.

668. Planes of Vibration in Sunbeam.—If we imagine a sunbeam to be cut by a plane perpendicular to the direction of the beam, we may suppose the section to consist of vibrations moving in every possible plane, as represented by Fig. 337. It is not to be supposed that all of these planes will intersect at the same point. There will be many rays whose planes of vibration are vertical, many whose planes of vibration are horizontal, etc.

FIG. 337.

669. Polarization by Absorption.—If a sunbeam fall upon a substance whose molecular structure allows vibrations in only a particular plane, say vertical, the substance may be compared to a frame with vertical bars, as represented by Fig. 338. Such a frame or such a substance will absorb the rays whose vibrations lie in a plane that is horizontal or nearly so, convert them into absorbed heat, and transmit, as polarized light, those rays whose vibrations lie in a plane that is vertical or nearly so. A plate cut in a certain way from a crystal of tourmaline acts in such a way; it is called a tourmaline analyzer. If the sunbeam fall upon a substance that allows vibrations in only a horizontal plane, the substance may be compared to a frame with horizontal bars, as represented in Fig. 339. Such a body will quench all the rays whose vibrations lie in a plane that is vertical or nearly so, and transmit, as polarized light, those rays whose vibrations lie in a plane that is horizontal or

FIG. 338.

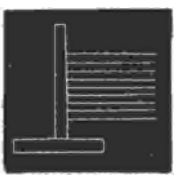


FIG. 339.

nearly so. The tourmaline analyzer previously used acts in this way when turned a quarter way around.

670. Tourmaline Tongs.—If these two frames, or two tourmaline analyzers, be placed one over the other in such a way that the bars of the second shall be perpendicular to those of the first, it will be seen that the first will quench or absorb part of the rays, while the rays transmitted by the first as polarized light will be quenched by the second. But if the bars of the second be parallel to those of the first, the polarized light transmitted by the first will also be transmitted by the second. This partial or total absorption of luminous rays is shown easily with the "tourmaline tongs," which consist of two tourmaline plates set in movable discs (Fig. 340). Light transmitted by either plate is polarized (and colored by the accidental tint of the tourmaline). When the plates are superposed, polarized light may be transmitted by both, or all of the incident light may be absorbed according to their relative positions as above stated.

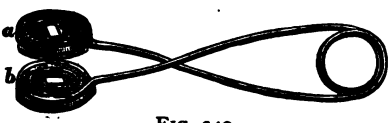


FIG. 340.

FIG. 341.

671. Polarization by Reflection. — Light is polarized when the rays whose vibrations lie in a particular plane are alone allowed to pass. This effect may be produced by causing a beam of light to be reflected by a non-metallic mirror at a certain angle which depends upon the nature of the reflecting substance. For glass, the ray must make

with the reflecting surface an angle of 35° 25′ (angle of incidence = 54° 35′).

672. Malus's Polariscope.—This instrument has two reflectors made of bundles of glass plates. Of these, *A* is called the polarizer and *B* the analyzer. Both reflectors turn upon horizontal axes; *B* also turns upon a vertical axis by means of the horizontal circles *CC*. When *A* and *B* are placed at the polarizing angle with the vertical axis, a beam of light is made to fall upon the polarizer in such a direction that the reflected light will pass vertically upward to *B*. This reflected light will be polarized. The polarized light will be reflected by *B* when the second reflector is parallel to the first (Fig. 343); it will be absorbed or transmitted when *B* is perpendicular to *A* (Fig. 342).

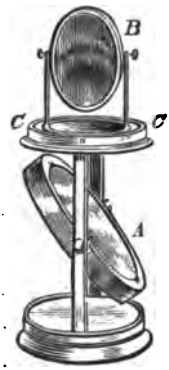


FIG. 342.

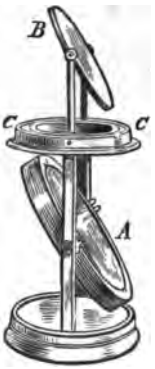


FIG. 343.

(*a.*) Place *B* as shown in Fig. 343. Throw a beam of light upon *A*, the room being darkened. The light reflected from *B* will form a white spot upon the side of the room. Turn the collar *C* slowly around. The spot of light will move around the sides of the room gradually growing fainter. When *C* has been turned a quarter way around (Fig. 342) the spot has wholly disappeared. Beyond this it grows brighter until *C* has been turned half way around, when it is as bright as at the beginning. When *C* has been turned three-quarters around, the spot again disappears, again reappearing as *C* and *B* are brought to their original positions.

673. Double Refraction.—We have seen that a plate of tourmaline may stop all rays whose vibrations lie in a certain plane while it allows passage to all rays whose vibrations lie in a plane perpendicular to this. A crystal of Iceland spar shows a different but very important effect upon an incident beam. The retardation of those vibrations whose plane is parallel to the axis (the line joining the two obtuse angles of the crystal) is different from the retardation of those vibrations whose plane is perpendicular to the axis. This difference in change of velocity produces a difference in the refraction of the two sets of rays. A beam of light, therefore, falling upon a crystal of Iceland spar will be generally split into two, producing the effect known as double refraction.

FIG. 344.

(*a.*) A small object, as a dot or line, viewed through a crystal of Iceland spar, will generally show two images formed by light oppositely polarized. If the eye be placed directly above the dot and the crystal slowly turned around, one image known as the ordinary image will remain stationary, while the other known as the extraordinary image will revolve about it at a varying distance. The ordinary ray has a constant and the extraordinary ray a variable index of refraction.

(*b.*) On looking at the two images formed by double refraction through a tourmaline or any other analyzer, it will be found that there is a marked difference in the brightness of the two images. As the analyzer is turned around, one image grows brighter and the other fainter, the greatest brightness of one being simultaneous with the extinction of the other.

Recapitulation.—In this section we have considered the Photographer's Camera and the human Eye; Microscopes and Telescopes; the Magic Lantern and the Stereoscope; Polarization of light by Absorption, by Reflection and by Double Refraction.

CONCLUSION.

ENERGY.

674. Varieties of Energy.—Like matter, energy is indestructible. We have already seen that energy may be visible or invisible (*i. e.*, mechanical or molecular), kinetic or potential. We have at our control at least eight varieties of energy.

(*a.*) Mechanical energy of position (visible, potential).
(*b.*) Mechanical energy of motion (visible, kinetic).
(*c.*) Latent heat (molecular, potential).
(*d.*) Sensible heat (molecular, kinetic).
(*e.*) Chemical separation (molecular or atomic; potential).
(*f.*) Electric separation (probably molecular, potential).
(*g.*) Electricity in motion (probably molecular, kinetic).
(*h.*) Radiant energy, thermal, luminous or actinic (molecular, kinetic).

675. Conservation of Energy.—The doctrine that, considering the universe as a whole, the *sum* of all these forces is a constant quantity, is known as the *Conservation of Energy.*

$$a + b + c + d + e + f + g + h = \text{a constant quantity.}$$

This does not mean that the value of a is invariable; we have seen it changed to other varieties as b or d. We have

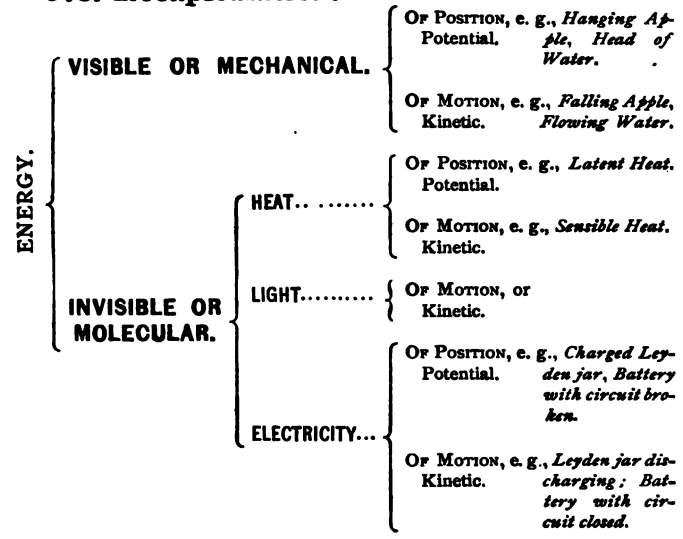
seen heat changed to electricity and *vice versa*, and either or both changed to mechanical energy. It does not mean that the sum of these eight variable quantities in the earth is constant, for we have seen that energy may pass from sun to earth, from star to star. But it does mean that the sum of all these energies in all the worlds that constitute the universe is a quantity fixed, invariable.

676. Correlation of Energy.—The expression *Correlation of Energy* refers to the convertibility of one form of energy into another. Our ideas ought, by this time, to be clear in regard to this convertibility. One important feature remains to be noticed. Radiant energy can be converted into other forms, or other forms into radiant energy only through the intermediate state of absorbed heat.

677. A Prose Poem.—"A river, in descending from an elevation of 7720 feet, generates an amount of heat competent to augment its own temperature 10° F., and this amount of heat was abstracted from the sun, in order to lift the matter of the river to the elevation from which it falls. As long as the river continues on the heights, whether in the solid form as a glacier, or in the liquid form as a lake, the heat expended by the sun in lifting it has disappeared from the universe. It has been consumed in the act of lifting. But, at the moment that the river starts upon its downward course, and encounters the resistance of its bed, the heat expended in its elevation begins to be restored. The mental eye, indeed, can follow the emission from its source through the ether, as vibratory motion, to the ocean, where it ceases to be vibration, and takes the potential form among the molecules of aqueous vapor; to the mountain-top, where the heat absorbed in vaporization is given out in condensation, while that expended by the sun in *lifting* the water to its present elevation is still unrestored. This we find paid back to the last unit by the friction along the river's bed; at the bottom of the cascade, where the plunge of the torrent is suddenly arrested; in the warmth of the machinery turned by the river; in the spark from the millstone; beneath the crusher of the miner; in

the Alpine saw-mill; in the milk-churn of the chalet; in the supports of the cradle in which the mountaineer, by water-power, rocks his baby to sleep. All the forms of mechanical motion here indicated are simply the parcelling out of an amount of calorific motion derived originally from the sun; and, at each point at which the mechanical motion is destroyed or diminished, it is the sun's heat which is restored."—*Tyndall.*

678. Recapitulation.



GENERAL REVIEW.

1. (*a.*) Define science, matter, mass, molecule and atom. (*b.*) How do physical and chemical changes differ? (*c.*) Define physics.

2. (*a.*) What are chemical and physical properties of matter? (*b.*) Define and illustrate two universal and one characteristic properties of matter.

3. (*a.*) Define meter, liter and gram. (*b.*) What is a solid, a liquid, and a gas? (*c.*) Define dynamics and force.

4. (*a.*) Name and define three units of force. (*b.*) Give Newton's Laws of Motion. (*c.*) Give the law of reflected motion.

5. (*a.*) Explain the parallelogram of forces, and (*b.*) the polygon of forces.

6. (*a.*) Define gravitation and give its laws. (*b.*) Give the law of weight. (*c.*) What is the centre of gravity, and how may it be found?

7. (*a.*) Describe Attwood's machine. (*b.*) Give the rules and formulas for falling bodies. (*c.*) How far will a body fall in three seconds?

8. (*a.*) What is a pendulum? (*b.*) Give the laws of the pendulum. (*c.*) How long must a pendulum be to vibrate 10 times a minute?

9. (*a.*) Define energy, foot-pound, dyne, erg, and horse-power. (*b.*) Deduce the formula for measuring kinetic energy when weight and velocity are given.

10. (*a.*) Define each of the six traditional simple machines. (*b.*) Give the law for each. (*c.*) What is the office of a machine? (*d.*) Discuss the subject of friction.

11. (*a.*) Give Pascal's law, and the rule for determining lateral liquid pressure. (*b.*) Describe the hydrostatic press, and state the general principle upon which its action depends.

12. (*a.*) State Archimedes' principle. (*b.*) What is specific gravity? (*c.*) Explain the determination of the sp. gr. of a solid lighter than water. (*d.*) Explain the use of the specific gravity bulb. (*e.*) Describe Nicholson's hydrometer and explain its use.

13. (*a.*) A 1000 gr. bottle having in it 928 grs. of water, has the remaining space filled with metallic sand and then weighs 1126.75. What is the sp. gr. of the sand? (*b.*) Through which of the three kinds of levers can the greatest power be gained? (*c.*) Through which can none be gained? (*d.*) Why do we use it? (*e.*) Give an example.

14. A ball projected vertically upward, returns in 15 seconds to the place of projection. How far did it ascend?

15. (*a.*) A floating solid displaces how much liquid? (*b.*) An immersed solid displaces how much liquid? (*c.*) A floating solid loses how much weight? (*d.*) An immersed solid loses how much weight?

16. What is the energy of a rifle-ball weighing 32 grams, having a velocity of 213 meters per second, and striking in the centre of a pendulum of wood weighing 23 kilograms?

17. (*a.*) What is meant by the increment of velocity or gravity? (*b.*) How far will a body fall in 6½ seconds? (*c.*) How far in the 9th second? (*a.*) If a freely-falling body have a velocity of 448 ft. per second, how long has it been falling?

18. (*a.*) Deduce, from the laws of falling bodies, the formula for

the velocity of spouting liquids ($v = 8.02\sqrt{h}$). (*b.*) Why must the unit of measure used with this formula be feet? (*c.*) Deduce a similar formula in which the meter is involved as the unit.

19. Name four kinds of water-wheels, and describe the most efficient of them.

20. (*a.*) Explain the action of the mercury barometer. (*b.*) Give Mariotte's law. (*c.*) Describe the piston of Sprengel's air-pump. (*d.*) Describe the ordinary air-pump. (*e.*) Explain the action of the siphon.

21. (*a.*) How would you illustrate the law of magnetic attraction and repulsion? (*b.*) Give the theory of magnetic fluids. (*c.*) What do you think of its accuracy and value? (*d.*) Explain magnetic induction.

22. If the capacity of the barrel of an air-pump be $\frac{1}{4}$ that of the receiver, how much air would remain in the receiver at the end of the fourth stroke of the piston, and what would be its tension compared with that of the external air?

23. What is the pressure on the side of a reservoir 150 feet long, and filled with water to the height of twenty feet?

24. (*a.*) Why is a reservoir usually built in connection with water-works? (*b.*) Why are fire-engines provided with an air-chamber? (*c.*) Why should the nozzle be smaller than the hose?

25. (*a.*) Why can you not raise water 50 feet with a common pump? (*b.*) What change would it be necessary to make in the pump in order to raise water to that height? (*c.*) Illustrate by a diagram.

26. (*a.*) Give the law of electrical attraction and repulsion, and illustrate by pith-ball electroscope. (*b.*) Define conductors and non-conductors, electrics and non-electrics. (*c.*) Illustrate by an example of each.

27. (*a.*) Give and illustrate each of the laws of motion. (*b.*) Explain composition and resolution of forces with illustrative figures.

28. (*a.*) Give the facts of gravity and the law of weight. (*b.*) If a body weigh 120 lbs. 2500 miles below the surface of the earth, at what distance above the surface will it weigh 80 lbs.?

29. Explain and illustrate electric induction fully.

30. (*a.*) Explain the construction and action of the electrophorus. What kind of electricity is discharged from it? (*b.*) Describe the Leyden jar and explain its action. (*c.*) Explain the action of the plate electric machine. (*d.*) In what way do lightning-rods protect buildings?

31. (*a.*) Discuss carefully the resistance of a Galvanic cell. (*b.*) Describe the Voltaic arc.

32. (*a.*) State the difference between a magnet and an electro-magnet. (*b.*) Give the principles on which the telegraph operates. (*c.*) What is meant by an "electro-negative substance?"

33. (*a.*) Describe Ruhmkorff's coil, and (*b.*) explain its action.

34. Describe the thermo-electric pile, and explain its use.

35. (*a.*) Give Prof. Tyndall's illustration of the propagation of sound. (*b.*) What is the velocity of sound in air? (*c.*) How is it affected by temperature?

36. (*a.*) Explain the difference between noise and music. (*b.*) Name the three elements of a musical sound, and state the physical cause of each.

37. (*a.*) Describe and explain the telephone. (*b.*) The phonograph.

38. (*a.*) Explain interference of sound. (*b.*) Give the laws of vibration of musical strings. (*c.*) Give the relative numbers of vibration for the tones of the major diatonic scale.

39. (*a.*) If 18 seconds intervene between the flash and report of a gun, what is its distance, temperature being 82° F.? (*b.*) If a musical sound be due to 144 vibrations per second, how many vibrations correspond to its 3d, 5th, and octave?

40. The bottom of a tank is 100 centimeters on one side, and a meter on the adjoining side. The tank has a depth of 50 centimeters of water. (*a.*) What is the pressure on the bottom? (*b.*) On either one of the vertical sides?

41. (*a.*) What is a horse-power? (*b.*) How many horse-powers are there in a machine that will raise 8250 lbs. 176 ft. in 4 minutes? (*c.*) State the modes of diminishing friction.

42. What will be the kinetic energy of a 25-pound ball that has fallen a mile? (Reject small remainders.)

43. Two bodies are attracting a third with forces as 441 to 576, the first, weighing 25 lbs., at a distance from the third of 20 feet, and the second at a distance of 30 feet; what is the weight of the second?

44. How far will a body fall in the first second on Saturn, the density of Saturn being .12 that of the earth, and its diameter being 72000 miles?

45. (*a.*) What is temperature? (*b.*) Discuss the expansion of water by heat. (*c.*) What is the rate of gaseous expansion by heat?

46. (*a.*) What is the difference between evaporation and boiling? (*b.*) What is the boiling point? (*c.*) What is distillation, and how is it performed?

47. (*a.*) Define latent, sensible and specific heat. (*b.*) What is the latent heat of water and of steam?

48. (*a.*) Explain the several modes of diffusing heat, showing how they differ. (*b.*) State and explain the relation between the absorbing and radiating powers of any given substance.

49. (*a.*) What is thermodynamics? (*b.*) State the first law of thermodynamics. (*c.*) What is the mechanical equivalent of heat in kilogrammeters? (*d.*) What does your answer mean?

50. (*a.*) Draw a figure showing the position of the parts of the cylinder and steam-chest when the piston is going up.

51. (*a.*) To what temperature would a cannon-ball weighing 150 lbs. and moving 1920 feet a second, raise 2000 lbs. of water from 32° F., if its motion were suddenly converted into heat? (*b.*) Explain the origin and propagation of sound waves.

52. (*a.*) Express a temperature of 50° F. in degrees centigrade. (*b.*) Name and describe the essential parts of a steam-engine in their proper order. (*c.*) Point out the changes in form of energy from the furnace fire, through a high-pressure engine to the heated axles set in motion thereby.

53. The mechanical equivalent of heat being 1390 foot-grams, the foot being equal to 30.48 *cm.*, and the increment of velocity on the earth being 980 *cm.*, find the mechanical equivalent in ergs.

Ans. 41519656.

54. (*a.*) What is the difference between waves of sound and waves of light? (*b.*) What is the difference between an athermanous and an opaque substance? (*c.*) What determines the apparent size of a visible object?

55. (*a.*) If the gun-cotton mentioned in § 555 (*a.*) be rubbed with a little lamp-black, will it be ignited with more or less difficulty? Why? (*b.*) What is reflection of light? (*c.*) How does it differ from refraction of light?

56. (*a.*) How could you show that light is invisible unless it enters the eye? (*b.*) What determines the apparent position of an object? (*c.*) What is the distinction between real and virtual images?

57. (*a.*) Describe and illustrate a construction for conjugate foci in the case of a concave mirror. (*b.*) In the case of a convex lens. (*c.*) What is meant by the index of refraction? (*d.*) Give the laws for refraction of light.

58. (*a.*) Explain total internal reflection. (*b.*) What is meant by dispersion of light? (*c.*) What is pure spectrum and how may it be produced? (*d.*) What are Fraunhofer's Lines and what do they indicate? (*e.*) Name the prismatic colors in order.

59. (*a.*) Why does a certain piece of glass look red when it is held between a lamp and the eye? (*b.*) Why does it look red when the lamp is between the glass and the eye? (*c.*) Explain the succession of colors in the rainbow. (*d.*) What three classes of rays in a sunbeam?

60. (*a.*) Describe the human eye as an optical instrument. (*b.*) The opera-glass. (*c.*) The terrestrial telescope. (*d.*) The stereoscope.

61. (*a.*) Explain polarization of light by absorption. (*b.*) By reflection.

62. (*a.*) Explain the action of the siphon. (*b.*) Find the volume of a balloon filled with hydrogen that has a lifting power of 440 lbs. (sp. gr. of air = 14.42. One liter of hydrogen weighs .0896 *g.*)

63. (*a.*) The barrel of an air-pump is $\frac{1}{4}$ that of the receiver; find the tension of the air in the receiver after 8 strokes of the piston, calling the normal pressure 15 lbs. and disregarding the volume of the connecting pipes. (*b.*) A stone let fall from the top of a cliff was seen to strike the bottom in $6\frac{1}{2}$ seconds; how high was the cliff?

64. (*a.*) A ship passing from the sea into a river, discharges 44800 lbs. of cargo, and is found to sink in the river to the same mark as in the sea. The sp. gr. of sea-water being 1.028, find the weight of the ship and cargo. (*b.*) A body weighing 12 lbs. (sp. gr. = $\frac{1}{4}$,) is fastened to the bottom of a vessel by a cord. Water being poured in until the body is covered, find the tension of the cord.

65. (*a.*) If the intensity of gravity at the moon be $\frac{1}{\text{5}\text{T}}$ of that at the earth, find the length of a seconds pendulum at the moon, the length of one at the earth being 39.1 inches. (*b.*) Find the maximum weight that can be supported by a hydraulic elevator connected with a reservoir, the area of the piston being 24 sq. in. and the reservoir being 170 ft. above the cylinder. (*c.*) The difference between the fundamental tones of two organ-pipes of the same length, one of which is closed at the top, is an octave. Explain why.

APPENDICES.

APPENDIX A.

Mathematical Formulas.

$\pi = 3.14159.$

Circumference of circle $= \pi D.$

Area of a circle $= \pi R^2.$

Surface of a sphere $= 4 \pi R^2 = \pi D^2.$

Volume of a sphere $\frac{4}{3} \pi R^3 = \frac{1}{6} \pi D^3.$

APPENDIX B.

Soldering.—The teacher or pupil will often find it very convenient to be able to solder together two pieces of metal. The process here described is very simple and will answer in most cases. A bit of soft solder, the size of a hazlenut, may be had gratis of any good natured tinsmith or plumber. Cut this into bits the size of a grain of wheat and keep on hand. Dissolve a teaspoonful of zinc chloride (muriate of zinc) in water and bottle it. It may be labelled "soldering fluid." If you have not a spirit-lamp obtain one, or *make one*. A small bottle (such as those in which school-inks are commonly sold) will answer your purpose. Get a *loosely* fitting cork and through it pass a metal tube about an inch long and the size of an ordinary lead pencil. Through this tube, pass a bit of candle wicking. Fill the bottle with alcohol, insert the cork, with tube and wick, and in a few minutes the lamp is ready. Having now the necessary materials you are ready for work. For example, suppose that you are to solder a bit of wire to a piece of tinned ware. If the wire be rusty, scrape or file it clean at the place of joining. By pincers or in any convenient way hold the wire and tin together. Put a few drops of "soldering fluid" on the joint, hold the tin in the flame so that the wire shall be on the upper side, place a bit of solder on the joint and hold in position until the solder melts. Remove from the flame holding the tin and wire together until the solder has cooled. The work is done. If you have a "soldering-iron," you can do a wider range of work, as many pieces of work cannot be held in the lamp flame.

APPENDIX C.

Centrifugal Force.—(See § 77.) Let a body placed at A receive an impulse which would push it in one second to D, while it is acted upon by a second force which in the same time would draw it to B. Then (see § 82) it will move through the diagonal AE. Inertia would then carry it in the line EF but the centripetal force draws it toward H and it describes a second diagonal EG. But the action of the centripetal force is continuous instead of intermittent as we have described it. Consequently, the moving body will change its direction at every point and describe a curve. Since ED, the distance that the body would have receded in one unit of time, is equal to AB, the two central forces are equal and the curve is a circle. If the arc AE be sufficiently small it will not sensibly differ from the diagonal AE. Since the triangles ABE and AEO are similar, we have

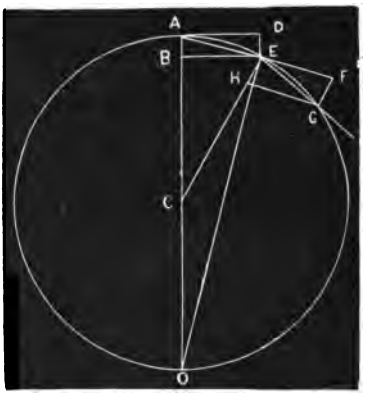


FIG. 445.

$$AB : AE :: AE : AO. \qquad \therefore \quad AB = \frac{AE^2}{AO}.$$

But AB represents the centripetal force and its equal the centrifugal, while AE represents the velocity, and AO the diameter or twice the radius.

$$\text{Hence the formula: C. F.} = \frac{v^2}{2r} \qquad (1.)$$

In this formula, C. F. represents a line, the distance over which the centrifugal force will move the given body. If we wish to measure this force by pounds or weight, we must compare it with the force of gravity, which is the cause of weight. A body, whose weight may be represented by w, will fall, when acted upon by gravity alone, 16.08 feet in one second. Hence:

$$w : \text{C. F.} :: 16.08 : \frac{v^2}{2r}. \qquad \therefore \quad \text{C. F.} = \frac{wv^2}{32.16r} \qquad (2.)$$

Letting t represent the number of seconds required to make one revolution,

$$t = \frac{2\pi r}{v}.$$

Remembering that $\pi = 3.14159$, we have

$$\text{C. F.} = \frac{1.2275wr}{t^2} \qquad (3.)$$

Representing the number of revolutions per second by n, we have

$$v = 2\ \pi rn. \qquad \therefore\ \text{C. F.} = 1.2275\ wrn^2.$$

Caution.—In using these last two formulas for "centrifugal force," care must be taken that radius be expressed in feet.

APPENDIX D.

Prince Rupert Drops.—A neat illustration of the transmission of pressure by liquids (§ 216), may be given by filling a small bottle with water, holding a Prince Rupert drop in the mouth, and breaking off the tapering end. The whole "drop" will be instantly shattered and the force of the concussion transmitted in every direction to the bottle which will be thus broken. These "drops" are not expensive; they may be obtained from N. H. Edgerton, 924 Chestnut street, Philadelphia.

APPENDIX E.

Difference between Theory and Practice.—The results mentioned in § 256 are never fully attained in practice. Only the particles near the centre of the jet attain the theoretical velocity. Further than this, if we carefully examine the stream we shall notice that at a little distance from the orifice the stream is not more than two-thirds or three-fourths the size of the orifice. This is due to the fact that the liquid particles come from all sides of the opening, and thus flow in different directions, forming *cross currents*, which may be seen if there are solid particles floating in the water. These cross currents impede the free flow and diminish the volume of liquid discharged. Short cylindrical or funnel-shaped tubes increase the actual flow. In a cylindrical tube, this narrowing of the jet could not take place without forming a vacuum around the narrow neck (called the *vena contracta*). The pressure of the atmosphere, tending to prevent this formation of such a vacuum, increases

the velocity and the volume of the discharge. The funnel-shaped tube prevents the formation of *cross currents* by leading the liquid more gradually to the point of exit.

APPENDIX F.

Barker's Mill.—A working model of this apparatus (§ 264) may be easily made by any wide-awake pupil. Select a long, sound lamp-chimney and a fine-grained cork that snugly fits the lower end. Take a piece of glass tubing, the size of a lead pencil, heat it intensely in an alcohol or gas flame until you melt off a piece a little shorter than the lamp chimney. By reheating the end thus closed by fusion, you may give it a neat, rounded finish. Prepare four pieces of glass tubing, each 12 *cm.* long. These pieces would better be made of tubing smaller than that just used. To cut the tube to the desired length, scratch the glass at the proper point with a triangular file, hold the tube in both hands, one hand on each side of the mark just made, knuckles uppermost and thumb-nails touching each other at a point on the tube directly opposite the file-scratch, push with the thumbs and at the same time pull with the fingers. The tube will break squarely off. Smooth the sharp edges by softening in the alcohol flame. Bend each of these four pieces at right angles, 2 *cm.* from each end, in such a way that one of the short arms may be in a horizontal plane while the other short arm of the same piece is in a vertical plane. The tubes may be easily bent when heated red-hot at the proper points in the alcohol or gas flame. See that the four pieces are bent alike. In the middle of the cork, cut a neat hole a little smaller than the tube first prepared. Near the edge of the cork, at equal distances, cut four holes a little smaller than the four pieces of bent tubing. Push the open end of the straight tube through the middle hole. From the other side of the cork, enter one end of each bent tube into one of the four holes. Place the cork with its five tubes into the end of the chimney, seeing to it that the straight tube lies along the axis of the chimney, *i. e.*, is parallel with the sides of the chimney. The closed end of the central tube should be near the open end of the lamp-chimney. In pushing the tubes into the cork, grasp the tube (previously dipped in soap and water) near the cork, and screw it in with a slow, rotary onward motion. See that the bent tubes are at right-angles to each other, like those shown in Fig. 91. For a support, take a piece of stout wire, small enough to turn *easily* in the central tube, and a little longer than the chimney. Place one end in the middle of a tin pepper-box and fill the box with melted lead. This makes a firm

base. File the other end of the wire to a sharp point. For a few cents, such a wire with an iron base may be had ready made at the stationer's. Pass the straight tube of the apparatus over this wire until the closed tube rests upon the sharpened point. The chimney with its four horizontal arms is now delicately suspended, free to revolve in stable equilibrium. Place the apparatus in the middle of a tub and pour water into the open end of the chimney. *Your* wheel will work as well as Edgerton's or Ritchie's. The satisfaction of seeing the machine work and knowing that you made it will amply repay the cost, leaving the instruction and added skill for clear profit.

APPENDIX G.

Balloons.—(See § 272.) A little thought concerning the full meaning of Archimedes' Principle will show that if a body weighs less than its own bulk of air it will rise in the air. Thus soap-bubbles filled with hydrogen or other light gas will ascend. If the bubble be made from hot water and filled with warm air it will rise; if it be made from cold water and filled with cold air it will fall. (Explain why.) The same principle applies to balloons. *A balloon will support a weight equal to the difference between the weight of the balloon with the contained gas and the weight of the air displaced.* A liter of hydrogen weighs 0.0896 *g.*; a liter of coal gas, from 0.45 *g.* to 0.85 *g.*; a liter of air heated to 200° Centigrade, about 0.8 *g.* During the siege of Paris in 1870, the Parisians communicated with the outer world by means of balloons about 50 feet in diameter, having a capacity of about 70,600 cu. ft. These balloons with net and car weighed about 1000 pounds each and had a carrying ability of about 2000 pounds. Balloons have been made about 100 feet in diameter, having a capacity of about half a million cubic feet. In 1861, an ascent was made to a height of seven miles.

APPENDIX H.

Atmospheric Pressure.—(See § 275.) Into a bent glass tube, *ACB*, pour mercury to a height of about 20 inches, or 50 *cm.* The mercury will, of course, stand at exactly the same level, *ac*, in the two branches. If equal pressures of any kind be exerted upon the surfaces of the mercury at *a* and *c*, this level will not be disturbed, while any difference of pressure would be promptly shown by the movement of the mercury and a consequent difference in the heights of the two mercury columns. The atmosphere presses

upon both mercurial surfaces, at *a* and *c*, but it presses upon them equally, and therefore does not change the common level. Into the arm *A*, push an air-tight piston, *p*, which has a valve opening upward but not downward. As this piston is pushed downward, the air in *A* escapes through this valve, and *p* finally rests upon the surface of the mercury at *a*. When the piston *p* is subsequently lifted to *A*, the atmospheric pressure is wholly removed from the surface of the mercury in that arm of the tube, while it acts with unchanged intensity upon the surface at *c*. The consequence is that the mercury follows the piston until there is a difference of about 760 *mm.* or 30 inches between the levels of the mercury in the two arms of the tube. If the tube have a sectional area of one square inch, the mercury thus supported would weigh about 15 pounds, and would exactly equal the weight of an air column of the same sectional area, reaching from the apparatus to the upper surface of the atmosphere.

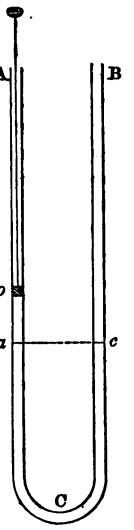


FIG. 446.

APPENDIX I.

Magnetic Needles.—Magnets may be made for the experiments described in § 306 by magnetizing three stout knitting-needles (see § 320). They may be suspended by means of a triangular piece of stiff writing-paper. Pass the needle through the paper near the lower corners; at the other corner affix by wax the end of a horse-hair, which will exert no torsion. The poles may be indicated by little bits of red and of white paper, fastened by means of wax to the ends of the needles.

APPENDIX J.

Dipping-Needle.—A dipping-needle may easily be made by thrusting a knitting-needle through a cork so that the cork shall be at the middle of the needle. Thrust through the cork, at right angles to the knitting-needle, half a knitting-needle, or a sewing-needle, for an axis. Support the ends of the axis upon the edges of two glass goblets or other convenient objects (see Fig. 131). Push the knitting-needle through the cork so that it will balance upon the axis like a scale-beam. Magnetize the knitting-needle and notice the *dip*. (See § 314 [*a*].)

APPENDIX K.

Electroscopes.—(See § 332.) For directions for making simple and efficient electroscopes, see Tyndall's "*Lessons on Electricity*," § 7. For an electroscope for the electrophorus (§ 342), provide a bit of wire about 8 *cm.* long, and bend it at right angles about 1 *cm.* from each end. Solder one of the bent arms of the wire (see Appendix B) to the upper side of the tinned plate, near its edge, in such a way that the central part of the wire shall be vertical. Cut a strip of gold-leaf (or Dutch metal) about 8 *cm.* long and 8 *mm.* wide. Moisten the *sides* of the free horizontal wire-arm with a little mucilage, place the middle of the gold-leaf strip over the top of the arm, and bring the ends of the leaf down to a vertical position, touching each other. The mucilage will hold the leaf to the wire. When the wire support and gold-leaves are electrified, the latter will diverge. When the apparatus is not in use, this electroscope may be protected by inverting a tumbler or beaker glass over it.

APPENDIX L.

Thermo-Electricity.—(See § 412.) The frame may be simplified by bending a strip of copper twice at right angles to make the top, bottom and one end of the frame, the other end being a cylinder of bismuth. But the form shown in Fig. 207 is preferable, as the same junction may be heated by the lamp below or chilled by laying a piece of ice on the upper side.

APPENDIX M.

Differential Thermometer.—(See § 482.) Prepare two boards, each 5 × 7 inches and an inch thick. Place them upon end parallel to each other, 7 inches apart. Connect the boards by nailing to their tops two thin strips, each an inch wide and 9 inches long. The strips will be 3 inches apart. This is our stand. For the two bulbs use two tin oyster cans with flat sides. To the centre of one end of each solder a tin tube, 1½ inches long and ⅜ of an inch in diameter. Take a 30-inch piece of glass tubing that will slide easily within the tin tubes. Bend it at right angles, 12 inches from each end, like the tube shown in Fig. 240. Color a little alcohol with red aniline, and pour into the bent tube enough to fill it an inch or two above each bend. Over each arm of the bent tube

pass an inch of snugly-fitting rubber-tubing, and slide it down about 8 inches. Pass the arms of the glass tube up through the tin tubes of the inverted cans as far as they will go. Slide the rubber tubing upward to make air-tight joints between the glass and the tin tubes. Place the cans upon the horizontal strips of the frame already made, allowing the glass tube to hang between the boards. The level of the liquid in either arm may be marked by a thread or rubber band that may be moved up or down.

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